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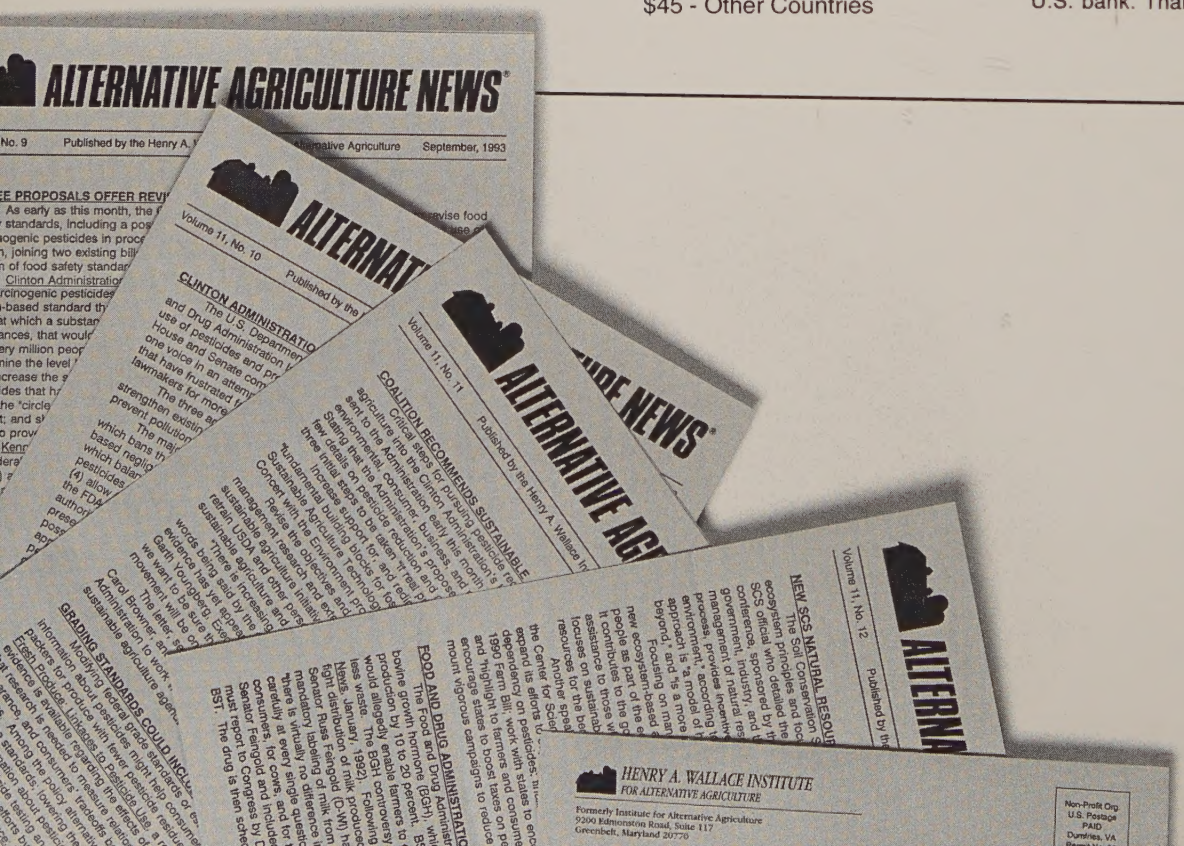

AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE®

1995
Volume 10, Number 4

TABLE OF CONTENTS

Articles

147 **Intensive rotational grazing for dairy cattle feeding** • J.W. Rust, C.C. Sheaffer, V.R. Eidman, R.D. Moon, and R.D. Mathison

152 **An overwintering cover crop increases inoculum of VAM fungi in agricultural soil** • L. Galvez, D.D. Douds, Jr., P. Wagoner, L.R. Longnecker, L.E. Drinkwater, and R.R. Janke

157 **A method for mechanically killing cover crops to optimize weed suppression** • N.G. Creamer, B. Plassman, M.A. Bennett, R.K. Wood, B.R. Stinner, and J. Cardina

163 **Environmental policy and swine manure management: Waste not or want not?** • Dana L. Hoag and Fritz M. Roka

167 **Economics of widespread manure application to irrigated crops: Raw and composted feedlot manure in eastern Colorado** • Erda Wang and Ed Sparling

173 **Economic analysis of an areawide program for biological control of the alfalfa weevil** • J.M. White, P.G. Allen, L.J. Moffitt, and P.P. Kingsley

180 **Adopting multidisciplinary approaches to sustainable agriculture research: Potentials and pitfalls** • C. Robert Stark, Jr.

184 **Trap cropping to manage the red sunflower seed weevil in oilseed sunflower** • Gary J. Brewer and Gene Schmidt

Departments

Institute News—151 • Upcoming Events—187 • Book Reviews—188 • Book Notices—191 • Resources—192

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Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

The cover shows dairy cows on the Muriel and Dan French farm in southeast Minnesota, where controlled, short-term grazing is used to rejuvenate streambanks and create grass-covered slopes. Photo by Craig C. Sheaffer, Dept. of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN.

DEDICATION

We proudly dedicate this issue of the **American Journal of Alternative Agriculture** to its very first Associate Technical Editor, Dr. Paul B. Marsh, who passed away in November, 1995. Paul was a devoted disciple of agricultural science who served with quiet distinction in the Agricultural Research Service of the U.S. Department of Agriculture (USDA) for over 40 years. Paul joined USDA in 1942 and received a Ph.D. degree in Plant Pathology from Cornell University in 1943. During his career, he authored or co-authored over 100 research papers and reports.

A writer with skill and compassion, Paul was a true friend who contributed a great deal to this **Journal**, especially during its formative years, a time when alternative agriculture was regarded with enormous skepticism by much of the conventional agricultural community. Paul lived by the belief that the role of science is to inform the public, not to take sides. His commitment to this goal encouraged others to think and to write with a clarity that contributed positively to the debate over the future of our food and agriculture system. He will be missed.

— Garth Youngberg, Editor in Chief

Intensive rotational grazing for dairy cattle feeding

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J.W. Rust, C.C. Sheaffer, V.R. Eidman, R.D. Moon, and R.D. Mathison

Abstract. *A 2-year study compared milk production and profitability for confinement feeding versus rotational grazing. Guernsey and Guernsey x Holstein cows grazed perennial grass pastures from mid-May to October or were fed in confinement. Averaged over both years, confined cows produced 7% more milk; their milk was similar in fat concentration to that of grazing cows. Body weight changes and health of the two groups were similar. Net return per cow averaged $64 higher for rotational grazing than for confinement because of lower costs for feeding, facilities, equipment, and labor. Intensive rotational grazing of pastures is a competitive alternative for dairy cow feeding. However, farmers in the northern U.S. will still require stored feeds from late fall through early spring.*

Key words: intensive grazing, confinement feeding, dairy, Voisin grazing

Introduction

Confinement feeding of dairy cows is an energy- and capital-intensive strategy involving mechanization of crop production and harvesting, extensive facilities for housing and feed storage, and grain feeding (Fales, 1993). Recently, increased costs for machinery, housing and feeding, combined with decreased milk prices, have greatly reduced the profitability of confinement dairy systems. Although increasing herd size may be an option to capture economies of scale, it clearly is not an acceptable alternative for many family dairy farms with herds of less than 100 cows and with limited assets.

There is renewed interest in use of low-input, pasture-based systems for dairy cow feeding (Parker et al., 1992). In contrast to traditional pasture management systems for dairy that use continuous grazing, many producers have adopted intensive (controlled) rotational or Voisin grazing systems to maximize production of quality pasture and to increase profit (Murphy et al., 1986). In intensive rotational grazing, farmers use portable fencing and watering systems in rotating the animals among paddocks to manage pasture growth and consumption. The lengths of the grazing periods and the rests between them are controlled by varying the size and number of the paddocks and the number of animals (Murphy, 1988).

Brown (1990) summarized the experiences at four Pennsylvania dairy farms practicing intensive rotational grazing. Compared with conventional confinement systems, intensive rotational grazing earned higher profits (because of lower feed and machinery costs), improved animal health and reproduction, and promoted better management of forages and animals. Its disadvantages were that it was more sensitive to the weather and required more labor to move the animals. Parker et al. (1992) used a whole farm model to compare pasture-based and confined feeding systems on a typical Pennsylvania dairy farm. Their analysis found that by using intensive rotational grazing, a farmer milking 53 cows could reduce total operating costs by $5310 and increase gross margin by $121 per cow. However, they concluded that intensive grazing was unlikely to expand unless milk production per cow could be maintained at a level similar to that of confined feeding and unless the relative price of concentrates, stored forage, and pasture changed to favor grazing.

In the north central United States, about one-fourth of the land is in permanent pasture. Pastures are generally underutilized and are not a large source of feed for milking cows. Efficient use of permanent pastures would enhance the sustainability of many dairy farms.

Although farmer surveys and whole farm models have been useful in showing the benefits of intensive rotational grazing, there is inadequate information from controlled studies that compare confinement and rotational grazing for dairy cows. Our objective was to compare these two systems' effects on dairy cow productivity and profitability during the grazing season. This study was conducted in northern Minnesota, where permanent grass pastures are abundant and dairy herds are usually less than 50 cows.

Materials and Methods

We compared rotational grazing and confinement feeding from 20 May to 3 October 1991 and from 11 May to 1 October 1992 at the North Central Experiment Station, Grand Rapids, Minnesota. Guernsey and Guernsey x Holstein cows that were lactating throughout the summer were allotted to the two treatments by pairing cows of similar age, genetics, stage of lactation, and pre-trial milk production. In 1991, 13 cows were allotted to each group; in 1992, 12 cows were assigned to rotational grazing and 9 cows to confinement feeding.

The confined cows were fed alfalfa haylage and corn silage free choice, 1.8 kg/day of alfalfa (*Medicago sativa* L.) hay,

Contribution of the Minnesota Agricultural Experiment Station, Pub. No 21,686. This research was partially supported by the North Central Region Sustainable Agriculture Research and Education Program.

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and concentrates. They were housed in a tie-stall barn except for 1 hour per day when they were in a dry lot to make it easier to detect those in heat. The rotationally grazed cows used pasture as the major source of forage plus 1.8 kg/day of alfalfa hay fed in the barn at milking. An exception occurred during 3 weeks in August 1991 when there was insufficient pasture because of drought, so that the rotationally grazed cows were fed alfalfa haylage to supplement the pasture. Both groups were fed energy and protein concentrates to balance their diets for individual milk production. Diets were balanced for energy and protein intake using the Professional Nutritionist software developed by the Minnesota Extension Service (Linn and Plegge, 1987). Concentrate feeding was changed every 4 weeks, using the previous week's milk production and the most recent analysis of feedstuffs fed to each group. Since we did not know the dry matter intake from pasture, in balancing the diets we assumed that the dry matter intake by the cows on pasture was the same as for the confined cows.

The pasture was a mixture of Kentucky bluegrass (*Poa pratense* L.) and quackgrass (*Elytrigia repens* L. Nevski) with some orchardgrass (*Dactylis glomerata* L.), reed canarygrass (*Phalaris arundinaceae* L.) and white clover (*Trifolium repens* L.). This pasture was typical of many unimproved or neglected pastures in northern Minnesota. Nitrogen fertilizer (52 kg/ha) was applied to the pasture in April and in late June in both years. Soil P (30 ppm) and K (120 ppm) were adequate for perennial grass pasture production. The 8.3-ha pasture was divided into seven sections, which were subdivided into paddocks using portable electric fencing.

We used a rotational grazing system where milking cows were rotated to a new paddock every 12 hours and returned to a grazed paddock in 16 days during rapid regrowth in May and June, and in 27 days during July, August, and September. In 1992, rotation back to grazed paddocks occurred about 3 to 5 days earlier than in 1991 because of very rapid grass regrowth. Grasses were always vegetative without seed heads at the start of each grazing period, and cows grazed about half the available forage before being moved to the next paddock. Height of residue varied from 7 to 12 cm after grazing by the milking cows. Heifers and dry cows were rotated through the pasture after the milking cows to achieve a more uniform stubble height.

The cows were milked twice a day and milk weights were recorded. We analyzed milk samples monthly for butterfat, protein and somatic cell count (which shows the level of infection or irritation in the udder). We recorded the following information on each cow: body weight at the beginning and end of the trial and monthly during the trial; feed consumption (except pasture) for individual cows throughout the trial; and a visual score for body condition on a scale of 1 to 5 at the beginning, midpoint and end of the trial. We also recorded grazing days and body weight of the dry cows and heifers used for followup grazing after the milking cows, but we did not use these data in the economic analysis and do not report them here.

We took representative forage samples from the paddocks the day before grazing and used them to balance the ration. The top half of the plant canopy in three randomly selected 1-m^2 sites was clipped and mixed to provide a sample from which we took a subsample for analysis. The samples were dried in a microwave oven and analyzed for acid detergent fiber (ADF) and neutral detergent fiber (NDF) using the procedures of Goering and Van Soest (1970), and for crude protein (CP). CP measures the total protein in a forage; ADF and NDF are components of the forage that are negatively associated with its digestibility and intake potential, respectively. Net energy for lactation is the net energy value of feeds for maintenance, gain, pregnancy, and milk production of lactating cows. We calculated net energy for lactation from ADF concentration (Linn and Martin, 1989).

Results and Discussion

Dairy cow performance

In 1991 and 1992, confined cows had greater milk production than grazing cows throughout the grazing season (Table 1 and Fig. 1). Averaged over both years, confined cows produced 7% more fat corrected milk (FCM); their milk was similar in fat concentration to that of grazing cows. Daily milk production declined for both groups as the season progressed, as expected with a normal lactation curve. Somatic cell counts were low and were similar for the two groups each year (average of 175,000 1991 and 308,000 in 1992). Average m protein, body condition scores (range 2.7 3.4), and body weight changes were simil for the two systems each year. The bo weight changes and body condition scor show that the cows in both groups we healthy and adequately nourished.

Cows on pasture consumed less gra than the confined cows because they som times refused grain, while confined co rarely did. The cows on pasture were in th barn for only two hours twice a day and th had less time to consume grain. We do n know how much pasture forage the grazin cows consumed. They may have consume more forage than the confined cows, whic may have reduced their intake of grain su plement. Reduced grain consumption p tentially results in less energy intake. Th may explain the lower production of mil and fat for the cows on pasture.

In grazing studies in Pennsylvania wit high producing Holsteins, milk productio dropped faster early in lactation and bod condition generally was poorer for grazin cows compared with conventionally fe cows, regardless of supplementation (Fale 1993). This happened because cows on pas ture consumed large amounts of grass an could not eat enough supplement to mee their protein and energy needs.

Pasture forage quality and yield

The average nutrient composition of th pasture forage (dry matter basis) for th 1991 grazing season was 18.5% CP, 31.9% ADF, 50.5% NDF, and 0.30 Mcal/kg ne energy for lactation. In 1992, average CP ADF, and NDF concentrations were 22.2% 27.9%, and 45.9%, respectively; net energy for lactation was 0.315 Mcal/kg. The quality of the forage improved in 1992 because grazing began at an earlier stage of pasture maturity and because the paddocks were ro tated more rapidly. Seasonal variation in pasture ADF, NDF, and CP reflects changes in maturity of the forage (Fig. 2).

In 1991, the 8.3 ha of grass pasture sup ported a daily average of 3.2 animal units (AU, 454 kg) per ha for the 137-day grazing season. An additional 11,300 kg of excess forage was harvested for hay in early June. The amount of forage available in late May and early June was considerably greater than later in the season. In 1992, the pasture

Table 1. Performance of rotationally grazing and confined dairy cows, May–September.

Variable	1991		1992		
	Grazing	Confined	Grazing	Confined	Residual S.E.
Milk production per cow (4% FCM, kg)[1]	2830	2971	3372	3675	44.4[2]
Average butterfat (%)	4.4	4.6	4.6	4.6	<0.1[3]
Average milk protein (%)	3.3	3.5	3.5	3.5	<0.1[3]

[1] FCM = fat corrected milk.
[2] Standard error of mean (43 df) after adjusting for effects of treatment, days in lactation and cow productivity at beginning of each year.
[3] Standard error of mean (46 df), combined over herds and years.

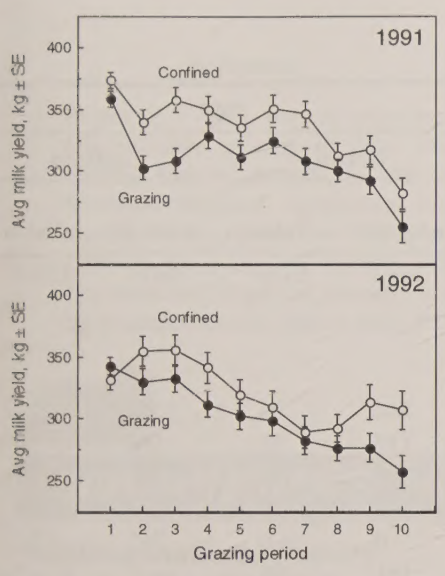

Fig. 1. The effect of rotational grazing and confinement feeding on milk production during 1991 and 1992. Grazing periods are 14 days.

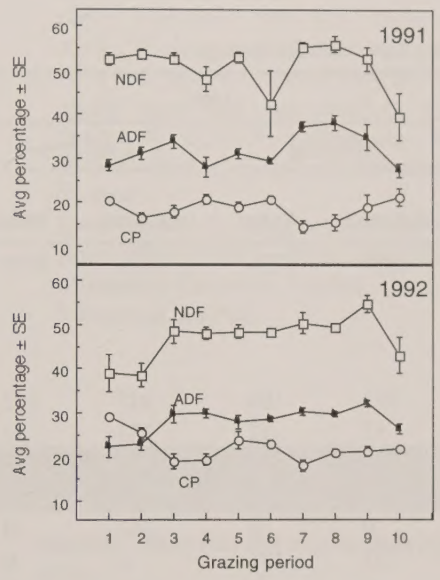

Fig. 2. Pasture crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentration in 1991 and 1992. Grazing periods are 14 days.

supported an average of 3.4 AU/ha over the 144-day grazing season.

The quality of available forage was reduced by drought during the seventh and eighth grazing periods in August 1991. More abundant and uniform rainfall and earlier grazing resulted in uniformly higher pasture quality in 1992 than in 1991. Milk production of grazing cows dropped in June 1991 (second grazing period) when the pasture matured, and increased when pasture quality improved during the third and fourth grazing periods.

Economic analysis

Net return per cow was $53 and $44 greater in 1991 and 1992, respectively, for rotationally grazed cows compared with confined cows (Table 3). The pasture system had lower gross receipts than the confined system both years because its milk production was 7% lower, but the lower costs of feeding, facilities and labor resulted in higher net return. The greatest cost reductions came from decreased use of facilities and equipment (54%) and from reduced labor (41%). The greatest expense for both systems was for feed and straw. With grazing, about 40% of the feed costs was the charge for pastures; this charge was computed as the return from forgone hay production. For some producers, this charge may be too high because their land could not have been harvested for hay.

Our results are restricted to a comparison during the grazing season and do not consider effects on year-round animal performance and economics. However, they support results from farm surveys (Parker et al., 1991) that reported 4% lower annual milk production and 7% lower production costs from pasture-based compared with confinement farms. Our two-year average increase in net return of about $48 per cow per year was less than the average potential saving of $121 to $153 reported in surveys of dairy producers in New York (Emmick and Toomer, 1991) and Pennsylvania (Parker et al., 1991). This may be related to several factors: the shorter grazing season in northern Minnesota; our use of primarily grass pastures; and the use of Guernsey and Guernsey x Holstein animals, which lack the milk production potential of Holsteins. Also, we did not credit the value of the hay ($11.53 per cow) harvested in 1991 or the forage removed by dry cows and heifers that followed the milking cows in rotation. This would have increased receipts and net returns for the grazing system.

The grazing system has several potential economic advantages over confinement. In the grazing system, cows are fed less corn grain, soybean meal, alfalfa haylage and corn silage, and machinery usage is lower. Therefore, profit is affected less in the grazing system than the confined system if feed and energy prices increase. Furthermore, the grazing system requires less expenditure for investments for buying, operating, and maintaining equipment, silos, and housing.

Summary and Conclusions

Intensive rotational grazing of pasture is competitive with confinement feeding as a strategy for milk production in northern Minnesota. Its net returns were greater because of reduced expenses for feeding and bedding, facilities, equipment and labor. Milk production per cow was less with grazing, but the condition and health of the cows were similar in the two systems.

We achieved our results with dairy cows that were unaccustomed to grazing and with personnel who were inexperienced in handling and feeding grazing cows. For example, in 1991 we learned the importance of early and timely grazing of pastures to maintain long-term pasture quality, and we adjusted our grazing practices in 1992. Consequently, continuing the experiment probably would have improved the performance of the grazing system. Our results probably

Table 2. Supplemental feed (kg DM/cow) consumed by rotationally grazing and confined dairy cows, May–September.

	1991		1992	
Feed	**Grazing**	**Confined**	**Grazing**	**Confined**
Corn grain	921	946	888	1060
Soybean meal	53	153	117	176
Hay	208	215	204	263
Haylage	136	1010	0	1225
Corn silage	0	362	0	245

also were influenced by pasture compos tion. Pastures with more legumes probabl would have resulted in improved anima performance compared with our predom nantly grass pastures because legumes hav greater intake potential than grasses (Lin and Martin, 1989). Legume composition o 30 to 50% of the pasture forage is recom mended in Minnesota. In addition, with N transfer from legumes to grasses (Russelle 1992), the need for N fertilization of th grasses would have been eliminated, whic would have further reduced productio costs for the grazing system.

Table 3. Receipts and expenses per cow for grazing and confined systems.[1]

			1991				1992			
			Grazing		Confined		Grazing		Confined	
	Unit	Price ($/unit)	Amount	Value	Amount	Value	Amount	Value	Amount	Value
Milk receipts	kg	.26/.29[2]	2830	$736	2971	$772	3372	$978	3675	$1066
Expenses										
Feeds and pasture										
Grain	kg	0.11	922	100	947	102	844	93	1060	117
Soybean meal	kg	0.22	53	12	153	33	117	25	176	39
Hay	kg	0.09	214	19	220	20	205	18	263	24
Haylage	kg	0.09	136	12	1039	94	0	0	1227	110
Corn silage	kg	0.05	0	0	362	18	0	0	245	12
Pasture[3]	AUD	0.67	153	103	0	0	161	108	0	0
Straw	kg	0.03	0	0	340	10	0	0	318	10
N fertilizer	kg	0.12	104	13	0	0	104	13	0	0
TOTAL				261		277		260		312
Facilities and equipment[4]										
Haylage	Mg	19.91	0.13	3	1.01	20	0.00	0	1.22	24
Corn silage[5]	Mg	19.91	0.00	0	0.36	7	0.00	0	0.24	5
Fencing[6]	ha	7.37	0.72	5	0.00	0	0.72	5	0.00	0
Tractor (90 hp)	hr	7.37	0.64	5	0.54	4	0.66	5	0.58	4
Manure spreading	hr	9.46	0.27	3	0.54	5	0.29	3	0.58	5
Mower	hr	8.35	0.37	3	0.00	0	0.37	3	0.00	0
TOTAL				19		36		16		38
Labor										
Routine care	hr	8.00	8.77	70	16.44	132	9.22	74	17.28	138
Build fence	hr	8.00	0.80	6	0.00	0	0.80	6	0.00	0
TOTAL			9.57	76	16.44	132	10.02	80	17.28	138
Net Returns				$380		$327		$622		$578

[1] All calculations are for a grazing period of 137 days in 1991, 144 days in 1992.
[2] The average of Minnesota monthly prices received by farmers for all milk during May through September: $0.26/kg in 1991, $0.29/kg in 1992.
[3] 1.12 AUD of grazing per cow is assumed for both years. A price of $0.67 per AUD was assigned to provide approximately the same net return per acre of pasture as would be obtained by producing hay.
[4] Hourly machinery costs are based on operating costs reported in Fuller et al. (1992).
[5] The annual cost per ton of silage storage is calculated as 10% of an investment cost of $198.97/Mg for a 6×18-m upright silo.
[6] The materials to fence 8.3 ha is $680 or $81.93/ha. The annual cost for depreciation, interest and repairs is estimated to be 20% or $16.39/ha.

In Minnesota, confined feeding is required for a minimum of 7 months each year. The investments already made in facilities, feeding systems, and harvest equipment for confined feeding, combined with the familiarity of the confined system, may deter many farmers from switching to grazing for part of the year. However, for new farmers, or farmers who want to expand existing facilities but are limited financially, rotational grazing may be a suitable option. Additional research is needed that examines the impact of grazing in a year-round, total farm system.

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INSTITUTE NEWS

Wallace Institute Report Refutes The "Newest Agricultural Myth"

A new report by the Wallace Institute challenges and refutes the "newest agricultural myth" — that chemically-based intensive agriculture will meet all of our production and environmental goals while feeding between 8–10 billion people in the next century. *Intensive Agriculture and Environmental Quality: Examining the Newest Agricultural Myth*, by Tracy Irwin Hewitt and Katherine R. Smith, presents well-documented, scientific evidence that challenges the assumptions and logic used by Dennis Avery, among others, to support this myth. The report argues that:

- The ecological impacts of chemically-based, intensive agricultural systems are serious and costly.
- The human health risks of pesticide-dependent, intensive agricultural systems are decidedly non-trivial.
- Chemically-based, land-intensive agricultural systems do not guarantee high productivity. They may not even sustain high yields.
- Sustainable and/or alternative agricultural production techniques often compete with and sometimes outshine their conventional counterparts.

"We challenge the agricultural research and business communities to investigate the full range of all possible pathways towards the goals of producing adequate food supplies for as many as 10 billion people in the next century," said the authors. According to the report, "no one technological paradigm or class of production systems is likely to prove optimal over all locations and circumstances. . . . A failure to pursue all the alternatives, and the possible synergies among them, is tantamount to irresponsibility."

Intensive Agriculture and Environmental Quality: Examining the Newest Agricultural Myth is $4 from the Henry A. Wallace Institute for Alternative Agriculture, 9200 Edmonston Road, #117, Greenbelt, MD 20770; (301) 441-8777; e-mail — hawiaa@access.digex.net

Thompson Farm Report Includes New Info On Weeds And Economics

"Alternatives in Agriculture," the 1995 report published by Thompson On-Farm Research and the Wallace Institute, includes new information on fertility, alternative weed management, and economics, and describes "successes and failures" that are meant to be "helpful to both farmers and the research community." Other chapters cover Inspiration, Documentation, and Education; Cover Crops; Crops; Water Quality — Soil Health; Livestock; and Farming for Better Communities. All the farm's experiments are described in table form at the end of each chapter. The publication of the report and the 1995 research is made possible by the financial support of Mrs. Jean Wallace Douglas through the Wallace Institute. Copies of the report are $10 plus $2 postage from Thompson On-Farm Research, 2035 190th St., Boone, IA 50036; (515) 432-1560.

Continued on page 183

An overwintering cover crop increases inoculum of VAM fungi in agricultural soil

L. Galvez, D.D. Douds, Jr., P. Wagoner, L.R. Longnecker, L.E. Drinkwater, and R.R. Janke

Abstract. *We conducted a field experiment within a low-input reduced tillage trial to determine how a cover crop affects inoculum levels of vesicular-arbuscular mycorrhizal (VAM) fungi. Plots with and without the hairy vetch cover crop were established on September 30, 1993, under moldboard plow (MP), chisel-disk (CD), and no-till (NT) treatments in low-input (LI) management, and MP in conventional (CONV) management. We conducted a 3-week colonization assay in the greenhouse with bahiagrass seedlings to assess the relative colonization potential of the soils in the fall and following spring. Hairy vetch roots were colonized by indigenous VAM fungi by 65 days after planting, with plants from NT being more colonized than plants from MP or CD plots. Spore populations were greater in the LI than in the CONV system. The beneficial effect of the cover crop on VAM spore populations in soil was manifested in the spring, with the* Glomus *type group more abundant in plots with cover than without it. The greenhouse bioassay showed that colonization potential of spring 1994 soil samples was higher in plots with cover than without cover for both the LI and CONV systems. Just one season of an overwintering cover crop of hairy vetch increased the inoculum of VAM fungi the following spring before the next cash crop was planted.*

Key words: cover crop, hairy vetch, sustainable agriculture, crop rotations, crop diversity

Introduction

Vesicular-arbuscular mycorrhizal (VAM) fungi are ubiquitous soil fungi that form a mutualistic symbiosis with the roots of most crop plants. Greenhouse experiments long have shown increased growth of mycorrhizal plants compared with nonmycorrhizal controls (Harley, 1989). The fungal hyphae outside the root act as extensions of the root system to aid in the uptake of immobile mineral nutrients such as P (Rhodes and Gerdemann, 1975). The fungi receive carbon compounds in return and are believed to be obligately dependent upon this source to produce new spores and hyphae and colonize more roots. Other research suggests VAM fungi also enhance their host's water relations (Davies et al., 1992), N uptake (Frey and Schuepp, 1993) and disease resistance (Schenck, 1987). The demonstrated benefits of VAM fungi mean that they should be crucial for adequate plant growth and economically acceptable yields when no chemical fertilizers and pesticides are used.

Compared with conventional practices, larger and more diverse populations of VAM fungi occur in low-input (LI) agricultural systems that do not use chemical inputs but that use diverse crop rotations and conservation tillage (Limonard and Ruissen, 1989; Sattelmacher et al., 1991; Douds et al., 1993). Various cultural practices contribute to this observation. Tillage affects both the distribution and efficacy of VAM fungi (An et al., 1990; McGonigle et al., 1990; Douds et al., 1995). Disruption of hyphae in the soil can decrease colonization of roots and mycorrhizae-mediated P uptake (McGonigle and Miller, 1993). Nonmycorrhizal plants in a crop rotation can decrease populations of VAM fungi (Harinikumar and Bagyaraj, 1988). Diversity of plant species in a crop rotation enhances VAM fungal diversity (Rabatin and Stinner, 1989). Greenhouse and field experiments have shown that chemical fertilizers, notably P, suppress colonization by VAM fungi and therefore their populations (Douds and Schenck, 1990; Kurle et al., 1991). Long-term fallowing suppresses populations of VAM fungi to the point of inhibiting the growth of the subsequent crop (Thompson, 1987).

Another factor that distinguishes LI from conventional agriculture is its use of overwintering cover crops to compete with weeds, retard soil erosion, supply fixed N and retain soil N. Overwintering cover crops potentially are very beneficial for VAM fungi. Since VAM fungi are obligate symbionts, warm, moist soil is not conducive to keeping them viable without plant hosts (Nemec, 1987; Douds and Schenck, 1991). Respiration rates of hyphae would increase and spores might be stimulated to germinate in warm soil, depleting their metabolic reserves. These conditions are possible in the autumn following crop senescence and in spring before sowing. Cover crops also are a reason that soils in LI farming systems are covered with living plants a significantly longer portion of the year than in conventional systems. This was suspected to be largely responsible for the higher populations of VAM fungi measured in LI than in conventionally managed soils (Douds, et al., 1993).

Mention of a brand or firm name does not constitute an endorsement by the USDA over others not mentioned.

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The objective of this study was to compare the VAM fungus colonization potentials of LI and conventionally farmed soils, each with and without an overwintering cover crop of hairy vetch (*Vicia villosa* Roth.). The cover crop would be an available host plant during periods of normally bare soil in conventional agriculture and should yield higher inoculum levels than plots without overwintering plant cover.

Materials and Methods

Experiments were conducted within the low-input reduced tillage trial at the Rodale Institute Research Center, Kutztown, Pennsylvania (Wagoner et al., 1993). Conventional (CONV) and LI wheat (*Triticum aestivum* L.)-corn (*Zea mays* L.)-soybean (*Glycine max* [Merr.] L.) rotations were established in 1988. Each farming system contains tillage treatments ranging from no-till to moldboard plowing. The CONV system relies on chemical fertilizers and pest control. Nutrient management and weed control in the LI system are achieved by cover crops grown between cash crops. Part of the experiment was used for this study. The dominant soil type was a Berks shaley silt loam (Typic Dystrochrept) with 160–200 kg/ha available P (Bray I).

Winter wheat was harvested from 12×30 m plots in July 1993 in fields under CONV and LI management. Hairy vetch was mechanically sown (260 seeds/m^2, row spacing 17.5 cm) on August 24 in moldboard plowed (MP), chisel disked (CD), and no-tilled (NT) plots as part of the LI rotation. Subplots (1-m^2) with and without cover were established by hand weeding on September 30, 1993, to learn if a lack of cover would depress inoculum levels. Four subplots per cover treatment were established in each of four blocks to yield 16 subplots per tillage × cover treatment combination in the LI system. Plots without cover were maintained by reweeding on October 5, 18, and 28, November 16, and April 20. In addition, on Oct. 1, 1993, hairy vetch was hand-sown into eight hand-hoed 1-m^2 subplots in a conventionally managed plot in the same field that had been moldboard plowed before the previous crop of winter wheat was sown. We also established eight subplots without cover by hand-hoeing, and maintained them as above.

We collected soil samples from the center of all subplots on October 5, 1993. The top 9 cm of soil was sampled using an 8-cm bucket auger. We isolated spores of VAM fungi by wet sieving (Gerdemann and Nicolson, 1963) and centrifugation (Jenkins, 1964), and characterized and quantified them. We counted only healthy-looking spores, that is, those whose contents were multi-vacuolate. The remaining soil then was mixed 1:1 [v/v] with vermiculite and potted into 165-cm^3 conical plastic pots ("Super cell C-10", Steuwe and Sons, Canby, Oregon). Bahiagrass (*Paspalum notatum* Flugge) seedlings were transplanted into the pots (one pot per subplot) and grown in a greenhouse under natural photoperiods and a temperature range of 10–30°C for three weeks. Entire root systems were cleared and stained for VAM fungi (Phillips and Hayman, 1970). We quantified colonization using the gridline intersect method (Newman, 1966). Hairy vetch roots were collected from the field on October 28, 1993, and assayed for VAM fungus colonization as above. We estimated ground cover for all plots at this time. On May 5, 1994, we collected soil samples and roots of hairy vetch, and assayed colonization, spore counts, and inoculum potential, as above. Data were also collected on ground cover, soil moisture (gravimetric after drying at 60°C for 48 h), and soil temperature.

We analyzed the data with ANOVA after transformation with arcsin (for percentage root length colonized) or SQRT(X+1) (for spore count). Characteristics for which significant treatment effects were seen were characterized further using Tukey's method of multiple comparisons (α=0.05).

Results

VAM fungus colonization of hairy vetch

Hairy vetch roots were well colonized by VAM fungi 65 days after planting (Fig. 1). Plants in the LI/NT treatment were significantly ($p<0.005$) more colonized than plants in the LI/MP and LI/CD treatments in the fall sample. Plants in the conventionally managed soils had the lowest colonization. Colonization levels for plants in the LI treatments in the spring sample were lower than those from the fall sample because of increased root growth, but maintained their relative rankings among the three different tillage regimes. In spring, colonization of hairy vetch roots in CONV management was as high as in the LI/MP and LI/CD treatments.

Plant cover, soil temperature and moisture

The percentage of ground covered by living plants (hairy vetch and weeds) estimated at the end of October showed how tillage affected plant establishment. The NT, CD, and MP plots had 100, 83 and 69% plant cover, respectively. Plots with a cover crop in CONV averaged only 3.5% because of their later planting date. All LI plots with hairy vetch showed full cover in May, while plots with a cover crop in CONV ranged between 10 and 60% cover (average of 39%). LI plots without a cover crop had between 0 and 20% cover (average of 3%) in the spring. Most of this was Canada thistle (*Cirsium* spp.) or dandelion (*Taraxacum officinale*). CONV plots without a cover crop remained free of plants.

Soil temperature was significantly ($p < 0.001$) greater in subplots without cover on May 5, 1994 (Fig. 2). No significant differences in soil moisture were found between covered and bare soil (24.3 and 23.9%, respectively).

VAM fungal spore populations

Spores isolated from soil samples were classified as *Glomus* spp. and placed in four groups: *Glomus occultum* Walker and *G. occultum*-like spores (LOCT); *Glomus etunicatum* Becker and Gerdemann and *G. etunicatum*-like spores (LETC); *Glomus fasciculatum* Thaxter and *G. fasciculatum*-like spores (LFSC); and other *Glomus* spp. as described by Douds et al. (1995). No spores were found that could definitively be placed in other genera.

Spore populations in the autumn 1993 samples reflected only tillage and farming system treatments because cover treatments were imposed only one week before collection of soil samples. Thus the results were pooled across cover treatment. Overall, populations of all spore type groups were lower in CONV than LI (Table 1). Among LI treatments, the LOCT and LFSC groups were more abundant in NT, while LETC and *Glomus*-type groups were more abundant in the CD treatment.

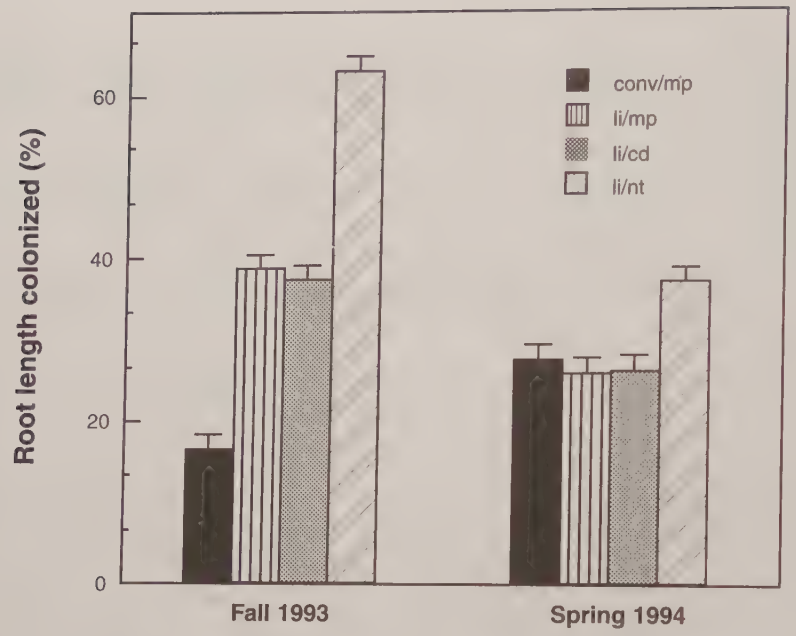

Figure 1. Colonization of roots of hairy vetch by VAM fungi. Roots were collected from the field on October 28, 1993 and May 5, 1994. Boxes represent means of 16 observations + SEM (LI/MP, LI/CD, LI/NT) or 8 observations + SEM (CONV/MP).

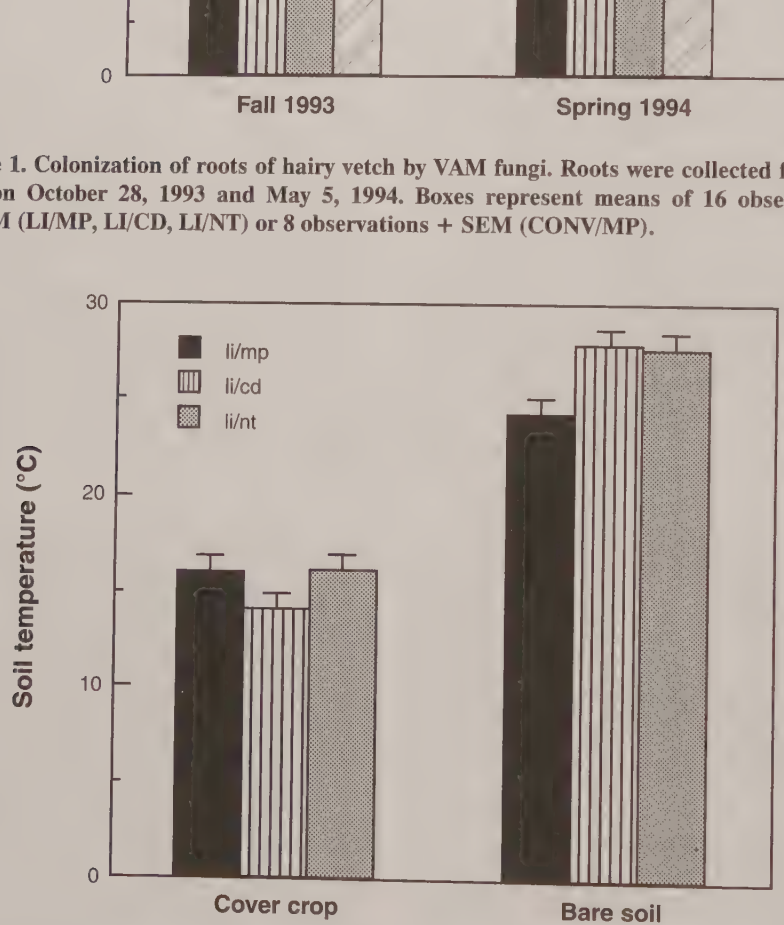

Figure 2. Soil temperature on May 5, 1994 in subplots with and without a cover crop of hairy vetch. Bars represent means of 16 observations + SEM.

Populations of all spore types in the spring 1994 samples were significantly affected by tillage regime in the LI system ($p = 0.0001$ to 0.023) (Table 2). Cover treatment had a significant effect only in the *Glomus*-type group ($p=0.0016$). The LETC group was more numerous ($p=0.081$) in covered plots in LI/NT and CONV/MP. Spores of the LFSC group exhibited a clumped pattern of distribution, resulting in large standard errors.

Colonization potential of the soil

The greenhouse bioassay with soil collected in fall, 1993 showed no significant differences in colonization of bahiagrass between plots with and without a cover crop in any LI tillage regime (Table 3) or in CONV management (Fig. 3). The soil from the conventional system had the lowest colonization potential of all samples. The colonization potential of the soil collected in spring 1994 was higher in plots with cover crop than in those without them in both the LI and CONV systems. The colonization of bahiagrass was higher (sometimes almost double) for soil collected in the spring than in the fall.

Discussion

An overwintering cover crop of hairy vetch significantly increased the inoculum of VAM fungi in soils from LI and CONV management compared with soils without a cover crop. Hairy vetch roots provided living plant hosts for VAM fungi during autumn and early spring growth periods. In addition, the colonization potential of all soils, as measured by the greenhouse bioassay, was greater in the spring than the previous autumn. Seasonal differences in environment in the greenhouse and relief of spore dormancy (Douds and Schenck, 1991) may have contributed to this observation. The cover crop also affected this phenomenon. The differences in colonization of bahiagrass between autumn and spring bioassays were much larger in soils from the hairy vetch-covered plots than in soils from bare plots. The largest increase from fall to spring occurred in the conventional plots, with 125 and 100% increases for the plots with and without cover, respectively.

Spore populations showed three general trends: larger numbers in the spring sample in plots with cover crops than in those without them; lower numbers in the spring than in the fall; and greater populations in LI than CONV. The beneficial effect of the cover crop was especially marked for the *Glomus*-type and LETC groups. The lower numbers of spores in the spring than in the fall may reflect normal mortality, since we counted only healthy-appearing spores. Other work at this site and elsewhere has shown higher populations of spores of VAM fungi under low-input than conventional management (Douds et al., 1993;1995).

The rapid colonization of hairy vetch roots by indigenous VAM fungi in the NT plots shows the importance of an intact

Table 1. Populations of VAM (50 cm^{-3}) spores in the soil of the cover crops experiment at the Rodale Research Center, (samples taken Oct. 5, 1993).[1]

Treatment	LOCT[2]	LETC[3]	*Glomus*	LFSC[4]
LI/MP	14.5c,A	11.8b,A	19.6b,A	0.3b,A
LI/CD	20.0b	18.4a	26.6a	0.5b
LI/NT	79.0a	8.1c	14.3c	9.3a
CONV/MP	8.6A	7.7B	4.9B	0.2A

[1] LI = low-input; CONV = conventional; MP = moldboard plow; CD = chisel-disk; NT = no-till. Lower case letters for comparisons within LI (means of 32 observations) by Tukey's method of multiple comparisons ($\alpha\pm$ = 0.05); upper case letters to compare CONV/MP (means of 16 observations) with LI/MP by the Bonferroni multiple comparison method (α = 0.05).
[2] *Glomus occultum* and *G. occultum*-like spores (hyaline, <100 µm diameter).
[3] *Glomus etunicatum* and *G. etunicatum*-like spores (yellow, <130 µm diameter).
[4] *Glomus fasciculatum* and *G. fasciculatum*-like spores (brownish, <85 µm diameter).

Table 2. Populations of VAM spores (50 cm^{-3}) in the soil of the cover crops experiment at the Rodale Research Center (samples taken May 5, 1994).[1]

Treatment	Cover	LOCT	LETC	*Glomus*	LFSC
LI/MP	yes	17.2±5.0	5.8±1.1	13.2±2.3	0.8±0.5
	no	13.0±1.6	6.2±1.0	9.0±1.6	0.5±0.3
LI/CD	yes	14.0±2.3	16.2±1.0	32.0±0.4	0.3±0.2
	no	12.0±0.8	18.2±6.7	19.8±3.1	0.3±0.2
LI/NT	yes	44.5±4.6	9.0±2.3	8.8±1.0	10.0±9.0
	no	72.2±9.3	3.8±0.8	7.5±1.6	1.8±0.8
CONV/MP	yes	5.8±1.0	6.5±1.5	4.5±1.4	0
	no	4.9±1.0	3.4±0.8	2.2±0.6	0

[1] Abbreviations as in Table 1. Means of 16 observations ± SEM.

Table 3. Colonization of bahiagrass roots (% root length colonized) with soil inoculum from the cover crops experiment.[1]

Treatment	Cover	Fall 1993	Spring 1994
LI/MP	yes	14.5±1.6	26.6±1.5
	no	13.7±1.7	21.6±1.9
LI/CD	yes	16.2±1.6	29.4±1.4
	no	15.9±1.9	26.2±1.8
LI/NT	yes	15.0±2.2	23.4±1.9
	no	17.5±3.0	18.5±1.0

[1] Abbreviations as in Table 1. Means of 16 observations ± SEM.

hyphal network in the soil as a significant component of the inoculum of VAM fungi. Fungal mycelium separated from the host plant survives only two to four weeks (Sieverding, 1991). Soil tillage disrupts fungal mycelium networks, which explains why, in the fall, colonization of hairy vetch roots was greatest under NT. The following spring, after a few months without soil disturbance, VAM hyphal networks recovered in cover crop plots, reducing the differences in colonization among the different tillage regimes.

Cover crops used as mulch maintain soil moisture, but under certain climates and management regimes they can deplete soil water needed for subsequent crops (Sarrantonio, 1994). In this experiment, the cover crop did not affect the soil moisture. Water loss from hairy vetch by transpiration may have counteracted the reduction in soil evaporation, leaving no net benefit. We collected soil only once for this measurement, and the outcome might be different for data collected throughout a growing season.

To recycle and use nutrients efficiently is a goal of sustainable farming systems. To achieve it, the system relies on diversified crop rotations that include cover crops, and on active microbial populations. Cover crops may have symbioses that fix atmospheric N or take up soluble, leachable nutrients and keep them in organic form until the cover is plowed or mowed. Also, we have shown that the cover crop serves as a host for VAM fungi during periods when the fungi might become nonviable. This study found that an overwintering cover crop of hairy vetch increased the VAM inoculum after just one season. Careful planning and management of farming systems to include the right sequence of cash and cover crops, as well as conservation tillage, will enhance levels of VAM fungi and contribute to the long term health of the soil and sustainability of the agricultural system.

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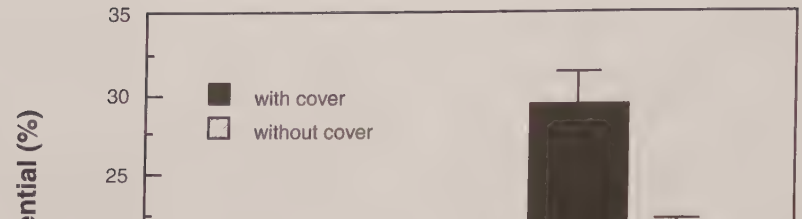

Figure 3. Percentage root length of bahiagrass colonized while grown in soil from CONV/MP plots with and without a cover of hairy vetch. Soil was collected on October 5, 1993 and May 5, 1994. Bars represent means of 8 observations + SEM.

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EPA Phases Out Pesticide Cyanazine

EPA has announced the phase-out over the next four years of the pesticide cyanazine for use in the United States. Cyanazine is an herbicide used on corn, cotton, and sorghum to control broadleaf weeds and grasses. EPA has classified cyanazine as a possible human carcinogen. DuPont Agricultural Products, the sole manufacturer of cyanazine, will cancel all cyanazine products effective December 31, 1999. EPA has instituted a schedule for significant reductions in use and exposure to cyanazine during the phase-out period prior to 1999. Growers will have time during this phase-out period to adopt substitutes for cyanazine.

A method for mechanically killing cover crops to optimize weed suppression

N.G. Creamer, B. Plassman, M.A. Bennett, R.K. Wood, B.R. Stinner, and J. Cardina

Abstract. *Residues of dead cover crops can suppress weeds by providing a mulch on the soil surface. The cover crop usually is killed with herbicides, but a mechanical method is desirable in systems intended to reduce chemical use. We designed and built an undercutter to kill cover crops by severing their roots while flattening the intact aboveground biomass on the surface of raised beds. We studied which cover crop species could be killed with the undercutter and compared the weed control potential of cover crop residues after flail mowing, sicklebar mowing, and undercutting.*

Whether a species was killed by the undercutter depended primarily on growth stage. Species that were in mid- to late bloom or beyond, including rye, hairy vetch, bigflower vetch, crimson clover, barley, and subterranean clover, were easily killed by undercutting. There were no differences in dry weights of broadleaf weeds between the undercut and simulated sicklebar mowed treatments, both of which had less weed biomass than the clean-tilled or flail-mowed plots.

Key words: cover crops, weed management, reduced-chemical systems

Introduction: Alternatives in Managing Cover Crops

Cover crops are often grown during the fall, winter, and spring in the north central United States to reduce soil erosion, improve soil chemical and physical properties, and aid in pest management. Specifically, winter annual cover crops can be an important source of biologically fixed nitrogen (N) (Hoyt and Hargrove, 1986). They also can help control soil erosion (Flach, 1990), improve soil physical properties (Beale et al., 1955; McVay et al., 1989), reduce nitrate leaching losses (Stivers and Shennan, 1989), add organic matter to the soil (Blevins et al., 1977), influence pest life cycles (Phatak et al., 1990), and suppress weeds (Teasdale, 1993).

There are several options for managing a cover crop in the spring. One is to incorporate it into the soil with a disk or moldboard plow. This is usually done two weeks before spring planting to conserve soil water and to initiate decomposition of the cover crop so that planting operations and seedling development are not impaired (Rodale Institute, 1992). A disadvantage is that the cover crop must be incorporated early in the season, when biomass production is still high. Wagger (1987) found that significant amounts of dry matter and N were forfeited when cover crops were killed in the third week of April rather than the first week of May. He reported that in North Carolina, hairy vetch (*Vicia villosa* Roth.) produced about 2000 kg/ha additional aboveground biomass and 58 kg/ha N in those two weeks.

Another option is to kill the cover crop and leave it on the surface as a mulch. This method exploits its weed control potential. Subsequent crops then are direct-seeded or transplanted into the killed cover crop. In most studies, herbicides have been applied to kill the cover crop or suppress it adequately (Sarrantonio and Scott, 1988; Raimbault et al., 1990; Reeves et al., 1993). Cover crops have also been suppressed by mowing (Dabney et al., 1991; Hoffman et al., 1993) or rolling (Vaughan et al., 1992) at the proper growth stage, but these methods have not been very successful or widely adopted.

To reduce herbicide use, alternative ways to kill the cover crop must be considered. Mowing with a flail-chop or rotary mower is the chief alternative, but it has some disadvantages. The small pieces generated with mowing decompose rapidly because they are in close contact with the soil and decomposing microorganisms. Therefore, they may not suppress weeds adequately for the entire season. Also, the cover crop's bulk is reduced compared with leaving it intact. Sicklebar mowing leaves the cover crop material intact but may not be possible with viney cover crops such as hairy vetch.

Production of processing tomatoes could benefit from cover crops managed to suppress weeds. Tomato is the leading processed vegetable in the United States, with Ohio the second biggest producer. Weed management can be especially difficult in vegetable crops because only a few herbicides are registered for use and because a high degree of control is necessary to

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maintain adequate yields. Weed control often is the main difficulty mentioned by growers who are trying to reduce chemical inputs.

The first objective of this study was to design and build an undercutter that would sever the cover crop's roots while flattening the intact aboveground biomass on the surface of raised beds. Raised beds are typical in tomato production in the Great Lakes region. Besides the benefit of having a thicker, longer lasting mulch on the surface, any weeds that were growing with the cover crop could be killed when the roots were severed by the undercutter. Our other objectives were to compare the effectiveness of the undercutter on various cover crop species and to compare the weed control potential of cover crop residues after flail mowing, sicklebar mowing, and undercutting.

Materials and Methods

Undercutter design and construction

On the basis of these considerations, we had three key design objectives for the undercutter: killing the cover crop; leaving the maximum amount of cover crop biomass on the soil surface and evenly distributed for optimum weed suppression; and minimizing soil disturbance to maintain an optimal seedbed for transplanting. The undercutter was designed for a typical processing tomato bed width (1.3 m) and for a depth no greater than 7.5 cm. The power requirements were compatible with tractors of 50 to 80 hp.

In 1992, we used an initial design to test the undercutter method on various cover crop species. The undercutting blade was a 1.5-m V-shaped blade from a standard blade plow used in wheat farming in the Great Plains. The blade was preceded by a 51-cm diameter coulter and followed by a rolling basket. There were two problems with this design. First, the V in the center of the bed left an opening in the mulch layer through which the weeds could germinate and develop. Second, the blade plow lifted the soil too high, forming large clods and making transplanting difficult. We redesigned the implement in 1993 to correct these flaws.

The new design (Figs. 1–3) had three components. The first consisted of two undercutting blades each of which worked half a raised bed. The blades were at 45° to the direction of travel to allow the material to flow well through the implement. The blade pitch was 15°, and each blade was at 5° from the horizontal (i.e., tilted downward toward the tip) to enable the blade tip to penetrate the soil sufficiently. The standards were on the outside of the bed to reduce soil disturbance. The position of the blade was adjustable from front to back and from side to side, which allowed flexibility in

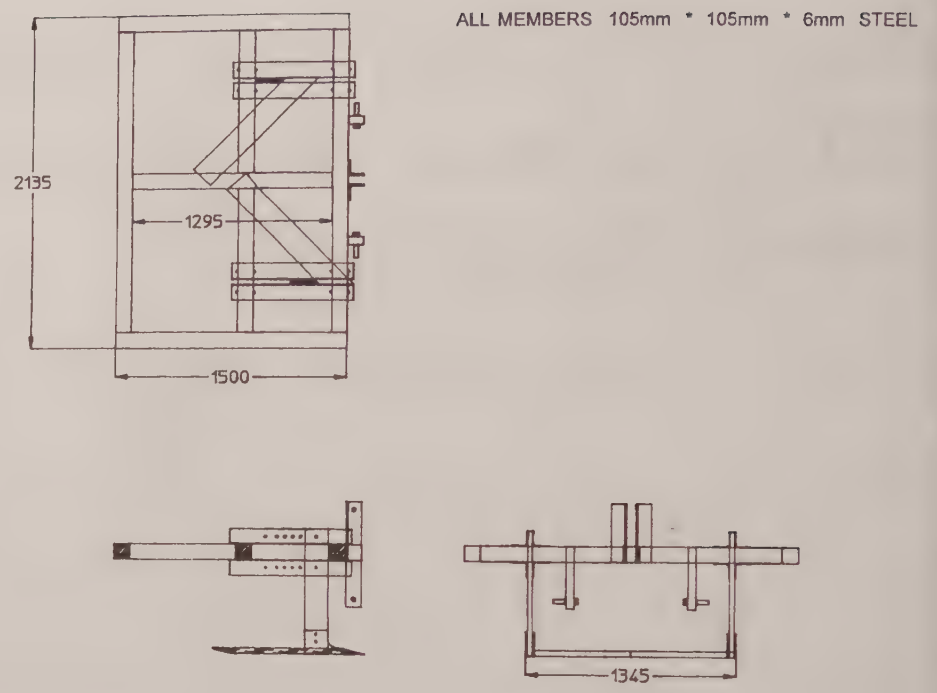

Fig. 1. Design of the undercutter frame with the blade, used for undercutting cover crops on raised beds.

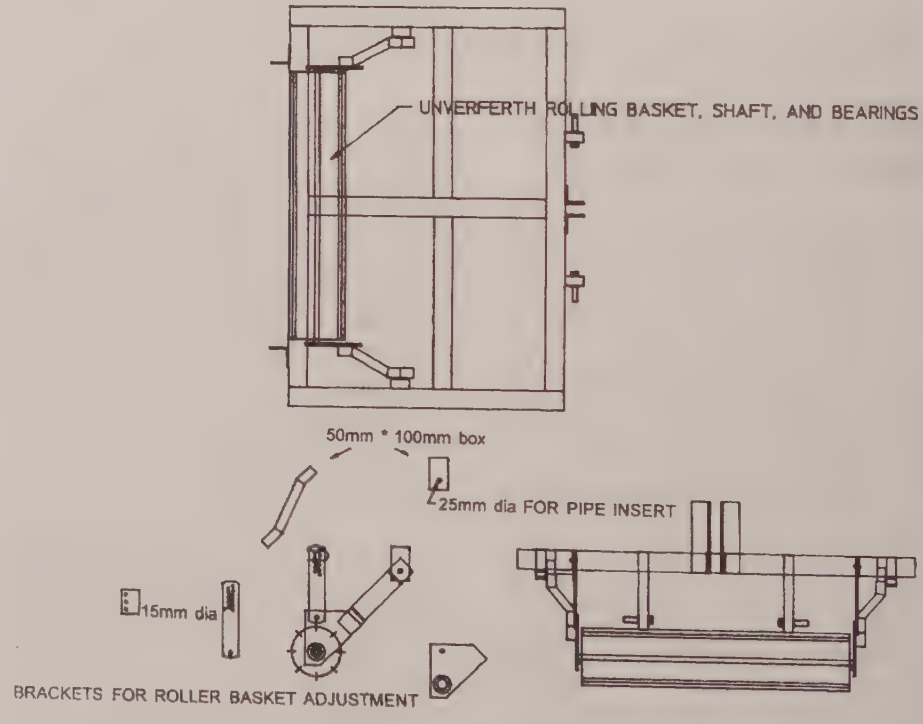
UNVERFERTH ROLLING BASKET, SHAFT, AND BEARINGS
50mm * 100mm box
25mm dia FOR PIPE INSERT
15mm dia
BRACKETS FOR ROLLER BASKET ADJUSTMENT

Fig. 2. Design of the undercutter rolling basket and mounting assembly.

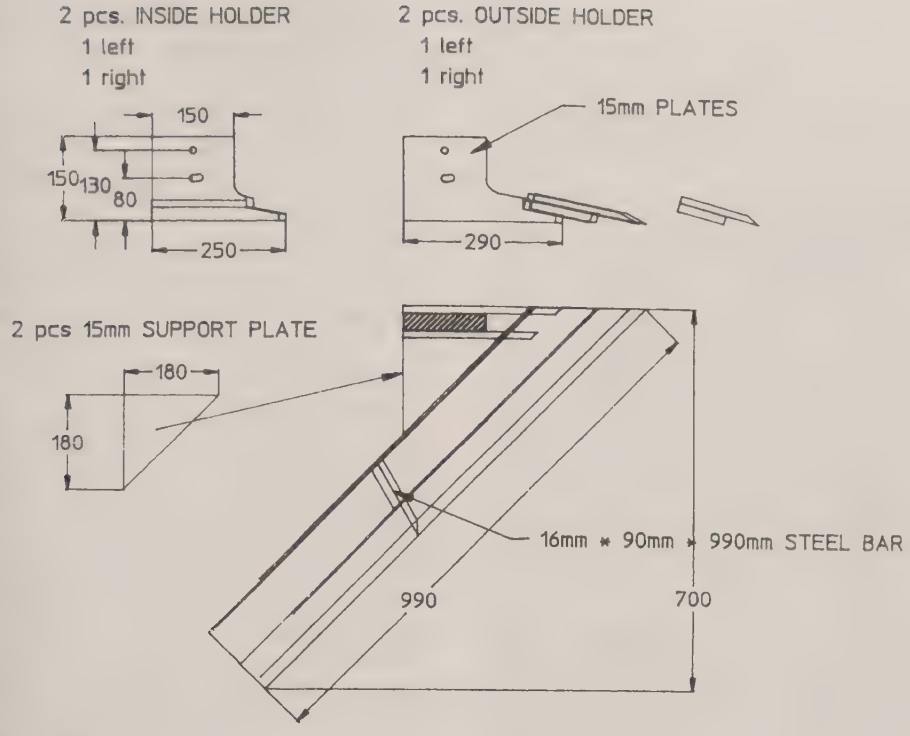

Fig. 3. Design of the undercutter blade holder pieces.

reducing plugging. The blades could be adjusted from a gap of 7.5 cm to an overlap of 15 cm where they met in the center of the bed.

The second component was a rolling basket to flatten and evenly distribute the undercut cover crop. The undercutter passed through the cover crop and left it nearly upright. We modified an Unverferth Mounted Rolling Harrow II (Unverferth Manufacturing, Kalida, Ohio) to lay the cover crop on the soil surface. An adjustable mounting assembly for the basket allowed the working depth of the undercutter to be adjusted from 2.5 cm above to 10 cm below the ground.

The third component was a three-point hitch frame for the other two components. To give high strength and adequate weight to hold the undercutter in the ground, the welded frame was constructed from 10×10-cm box steel tubing with 6 mm thick walls. Photographs of the undercutter are shown in Fig. 4.

Experiment 1: Effectiveness of the undercutter in killing cover crops

In spring, 1992, we used the undercutter on 17 species of cover crops (Table 1) to determine which could be managed effectively and killed using this new method. Cover crop species were evaluated at Columbus (OSU Horticulture Farm, central Ohio) and in Fremont (Ohio Agricultural Research and Development Center's Vegetable Crops Branch, northwest Ohio). The soil type in Columbus is a Miami silt loam; in Fremont it is a Colwood fine sandy loam. The experimental design at both locations was a randomized complete block with four replications. The data were analyzed with analysis of variance, with LSD tests used to separate means (Wilkinson, 1990).

Cover crops were planted in mid-August 1991 on 3.0-m long raised beds with 1.5-m centers. We hand-planted them in various mixtures, because mixtures may enhance some of their benefits (Creamer et al., 1992). The larger-seeded species were raked to a depth of 2.5 cm, and the smaller seeded species were just lightly covered. We inoculated all legumes with the appropriate *Rhizobium* spp.

The undercutter was used on May 16, 1992, in Columbus, and May 22, 1992, in Fremont. Many of the cover crops were already in mid-bloom or beyond; to delay undercutting much later than the end of May is not feasible in Ohio, considering the need for timely transplanting of subsequent crops. The working depth varied from 5 to 15 cm, and the operating speed was 1.6 to 3 kph. We chose the slow speed partly to be able to observe better, not out of necessity.

The cover crops were evaluated two weeks later to estimate the effectiveness of the undercutter. We used a kill of greater

Table 1. Cover crop species and seeding rates evaluated in 1991/1992 for ease of mechanical kill in Columbus and Fremont.

Species	Scientific Name	Seeding Rate (kg/ha)
Legumes		
Austrian Winter Peas	*Pisum arvense*	36.0
Clover, Crimson	*Trifolium incarnatum*	9.0
Clover, Ladino	*Trifolium repens*	1.35
Clover, Mammoth Red	*Trifolium pratense*	6.75
Clover, Medium Red	*Trifolium pratense*	6.75
Clover, Subterranean	*Trifolium subterraneum*	18.0
Sweetclover, Yellow Blossom	*Melilotus officinalis*	4.5
Sweetclover, White Blossom	*Melilotus alba*	4.5
Vetch, Bigflower	*Vicia grandiflora*	18.0
Vetch, Hairy	*Vicia villosa*	18.0
Non-legumes		
Barley	*Hordeum vulgare*	30.35
Fescue, Tall	*Festuca arundinacea*	2.7
Orchardgrass	*Dactylis glomerata*	3.4
Rye, 'Wheeler'	*Secale cereale*	27.0
Ryegrass, Annual	*Lolium multiflorum*	2.0
Ryegrass, Perennial	*Lolium perenne*	2.0
Wheat	*Triticum aestivum*	27.0

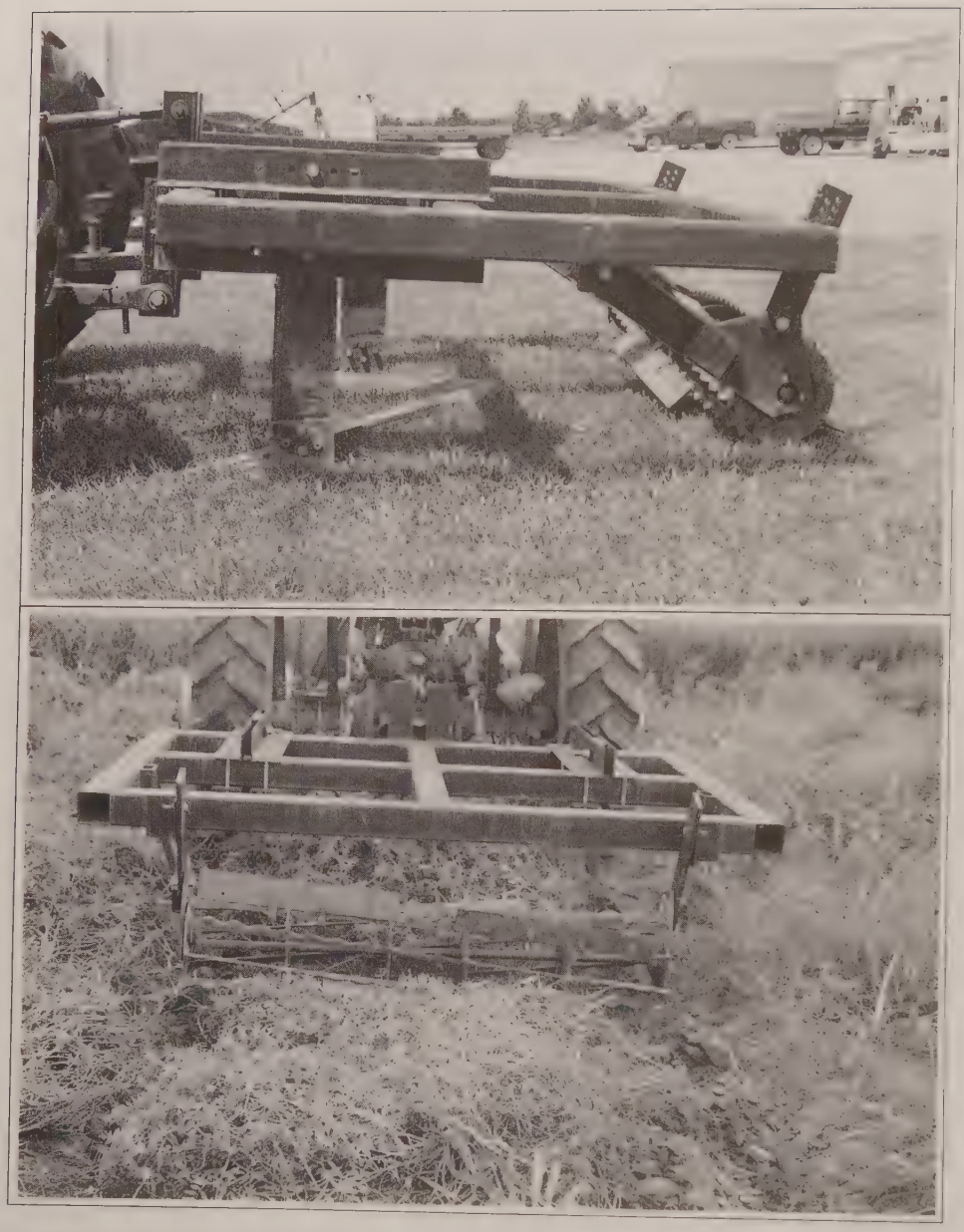

Fig. 4. Top: Side view of undercutter implement for mechanically killing cover crops. Bottom: Undercutter cutting through stand of hairy vetch, rye, crimson clover, and barley.

than 95% as the standard for success; otherwise, regrowth could be a problem in subsequent crops.

Experiment 2: Weed suppression by cover crop mulches killed by different methods

In this experiment we used four cover crop species that were killed successfully by the undercutter in 1992. On August 26, 1992, a mixture of hairy vetch, rye, barley and crimson clover was seeded in Columbus on raised beds by the same method as in 1991, at rates of 22.5, 27, 27, and 11.2 kg/ha, respectively. Plots were raised beds, 15.3 m long on 1.5 m centers. The experimental design was a randomized complete block with four replications and four treatments: killing the cover crops with an undercutter, flail mower, or sicklebar mower; and rototilling with no cover crop.

We chose these treatments to determine the differences in weed control potential between shredding the cover crop and leaving it intact (flail mower versus undercutter or sicklebar mower) and, for implements that leave the aboveground cover crop intact, between severing and not severing the weed roots (undercutter versus sicklebar mower). The rototilled plots were weedy checks to determine how effectively the cover crops suppressed subsequent weeds.

In this experiment, the sickle bar mower would not cut through the cover crops without clogging. Therefore, sicklebar mowing was simulated by cutting the cover crops at their base with machetes and laying the residue evenly over the surface of the bed. We assume that the sicklebar mower did not work because its blades were dull; however, hairy vetch is viney and might clog a sicklebar mower even with sharp blades.

The cover crop was killed and the clean tillage treatments were carried out on May 26, 1993. We measured weed densities in three 0.5-m^2 frames per plot on June 10 and June 24 (2 and 4 weeks after planting). Aboveground weed biomass was collected from 0.5-m^2 areas (4 per plot) on August 6 (10 weeks after planting). Broadleaf and grass weeds were separated, dried at 65°C for 48 hr and weighed. We measured only annual weeds in this study. The few patches of perennials already established were removed periodically by hand.

Results and Discussion

Experiment 1

Table 2 gives rainfall and temperatures for both study years. Whether a species was killed by the undercutter depended primarily on growth stage. Species that were in mid- to late bloom or beyond, which included rye, hairy vetch, bigflower vetch, crimson clover, barley, and subterranean clover, were easily killed (Table 3). This agrees with other studies that attempted to kill cover crops mechanically (Dabney et al., 1991). All species responded similarly at both sites except Austrian winter peas and wheat, which were killed in Columbus but not in Fremont. Both species were further developed in Columbus, which may explain this difference. Also, because they were killed by desiccation, species with more biomass or a higher water requirement may not have been able to regenerate their roots fast enough to get enough water to recover. The undercutter method, though not effective for all species, was successful for two of the cover crops most often grown in Ohio (hairy vetch and rye). The undercutter left an evenly distributed mulch on the soil surface.

Table 2. Monthly precipitation (cm) and minimum and maximum temperatures (°C).

	1991/1992						1992/1993					
	Columbus			Fremont			Columbus			Fremont		
	Prec.	T_{min}	T_{max}	Prec.	T_{min}	T_{max}	Prec.	T_{min}	T_{min}	Prec.	T_{min}	T_{max}
August	4.19	15.0	30.6	4.55	14.4	28.3	7.54	14.4	26.4	7.19	12.3	25.3
September	6.02	12.2	26.1	4.88	8.9	24.4	6.38	11.2	24.1	15.16	9.0	23.0
October	3.25	6.1	21.1	11.51	8.9	18.9	4.45	4.2	17.1	4.95	2.6	15.7
November	1.42	–1.1	9.4	4.88	–1.7	7.8	11.40	2.6	9.5	15.06	0.6	8.2
December	9.70	–3.3	6.7	3.20	–4.4	4.4	3.05	–2.7	4.7	7.67	–4.3	3.4
January	3.48	–3.3	3.9	2.95	–7.2	1.7	11.38	–2.9	4.6	8.08	–2.2	2.3
February	2.11	–0.6	7.2	4.29	–5.0	3.9	4.42	–7.7	2.1	4.01	–11.1	–0.5
March	8.74	–0.6	10.6	5.99	–4.4	7.8	6.17	–1.2	7.7	7.90	–3.8	3.9
April	6.76	5.5	16.7	6.02	1.7	13.9	14.91	4.3	15.5	8.00	1.4	13.2
May	8.59	8.3	22.2	7.85	7.2	20.6	7.39	9.6	23.4	2.46	8.2	22.0
June	6.35	13.3	25.6	10.90	11.1	23.9	11.94	15.2	26.8	11.15	13.9	25.3
July	26.77	17.2	27.8	14.68	15.0	26.7	14.86	19.1	30.1	3.48	16.7	29.8

Table 3. Ability of the undercutter to kill various cover crop species adequately (95%), 1992.

Species	Columbus	Fremont
Legumes		
Austrian Winter Peas	yes	no
Clover, Crimson	yes	yes
Clover, Ladino	no	no
Clover, Mammoth Red	no	no
Clover, Medium Red	no	no
Clover, Subterranean	yes	yes
Sweetclover, Yellow Blossom	no	no
Sweetclover, White Blossom	no	no
Vetch, Bigflower	yes	yes
Vetch, Hairy	yes	yes
Non-legumes		
Barley	yes	yes
Fescue, Tall	no	no
Orchardgrass	no	no
Rye, 'Wheeler'	yes	yes
Ryegrass, Annual	no	no
Ryegrass, Perennial	no	no
Wheat	yes	no

Experiment 2

All four cover crop species were effectively killed (95%) by all three mechanical methods (data not shown). The mulch left by the undercutter and the simulated sicklebar mowing was approximately 10 to 13 cm thick, whereas the mulch remaining after the flail mowing was 2.5 to 5 cm thick.

There were no differences in weed densities among cover crop management methods at either date (Fig. 5). Populations of grass weeds, predominately yellow foxtail (*Setaria lutescens*), were low. There were no differences ($p < 0.05$) between the undercutter and the simulated sicklebar mower in dry weight of broadleaf weeds, primarily common lambsquarters (*Chenopodium album*) and redroot pigweed (*Amaranthus retroflexus*). However, both had less weed biomass than the clean-tilled or flail-mowed plots (Fig. 6). This illustrates that cover crop residues suppress weeds more effectively when left intact.

There was no difference in how well the undercutter and the sicklebar mower suppressed weeds in this study. However, the sicklebar mowing was simulated, and the results may not represent the response to real mowing.

Conclusions

The undercutter's ability to kill cover crops and create a thick, evenly distributed mulch is encouraging. Species that were in mid-bloom and beyond were more susceptible to being killed by this method. The bed was disturbed only slightly, and in a related study a mechanical transplanter could transplant tomatoes directly through the mulch. In that study, the mulch remained throughout the season, controlling weeds as effectively as herbicides (Creamer et al., 1993).

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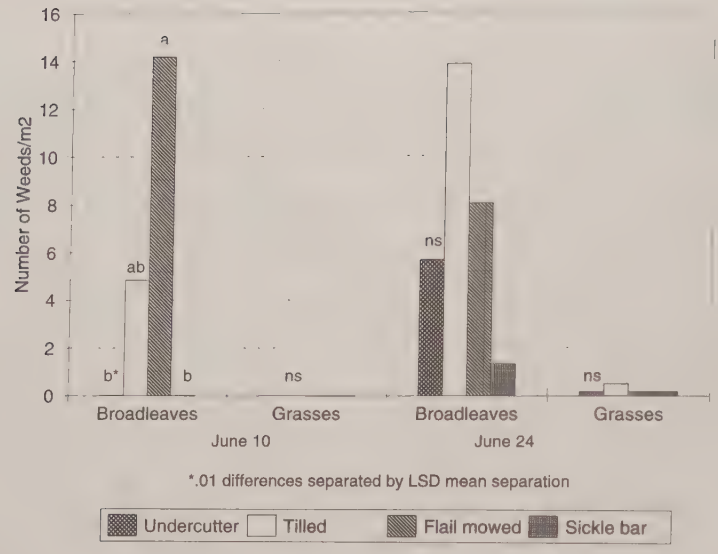

Fig. 5. Number of broadleaves and grasses emerging through dead cover crop mulch on June 10 (2 weeks after killing) and June 24 (4 weeks after killing), Columbus, 1993.

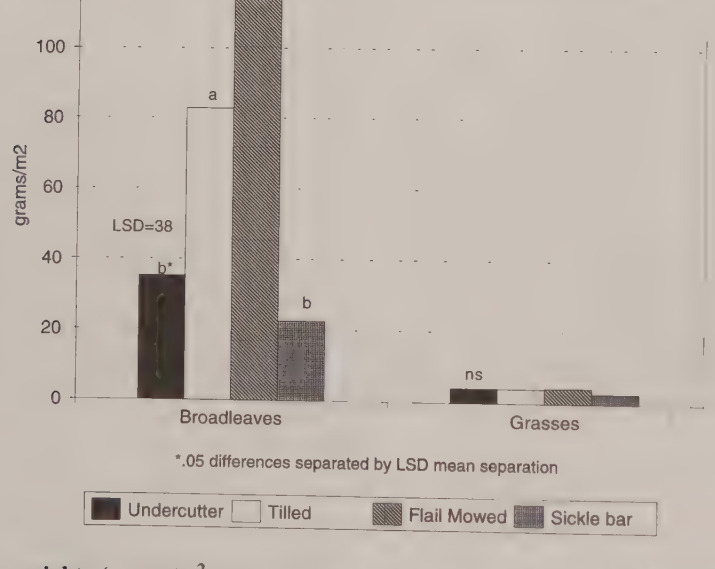

Fig. 6. Dry weights (grams/m^2) of broadleaves and grasses on August 6, 1993 (10 weeks after killing), Columbus.

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Environmental policy and swine manure management: Waste not or want not?

Dana L. Hoag and Fritz M. Roka

Abstract. *Livestock production and manure handling decisions often have been treated in the literature as separate enterprises. Policymakers, too, have ignored the interactive nature of manure management by focusing on land application for nutrient disposal. This study outlines a systems approach to describe the interrelated decisions producers face, using examples from North Carolina and Iowa that show how producers' attitudes toward manure management lead them to handle manure differently in different regions. In North Carolina, nutrients in manure are "not wanted." There are economic incentives to treat manure, thus reducing its nutrient content, and to apply it on as little land as possible. In Iowa, nutrients are "not wasted." Producers conserve the nutrients in manure and use them more fully, applying manure to higher value crops such as corn. Policies that influence manure management can be made more effective by accounting for the differences in producers' incentives to waste or want the nutrients.*

Key words: hogs, manure handling, nutrient management, land application, North Carolina, Iowa

Introduction: Changes in Swine Production

The U.S. hog industry is undergoing a radical restructuring as production shifts toward fewer but more highly concentrated facilities. This shift has been particularly noticeable in North Carolina, where production has doubled in the last ten years (North Carolina Dept. of Agriculture, various years). Only about 13% of North Carolina farms with hogs produce over 95% of the state's market hogs (Hurt and Zering, 1993). Economies of size in buildings and improved knowledge of nutritional and medical requirements provide sound economic justification for concentrating production. Nevertheless, several important issues have surfaced with respect to manure handling, among the most contentious being possible environmental damage. Larger manure stocks make proper manure handling much more difficult. Concentration of manure stocks increases the potential nutrient loading rates on surrounding land and threatens water quality. Also, considerable public attention has been directed toward odors from large confined swine facilities.

The changing structure of the swine industry has spurred a need to review manure management policies to insure that the environment is adequately protected without reducing farm profits. However, policy goals regarding manure are ambiguous. Proponents of sustainable agriculture argue for using manure stockpiles more aggressively in crop production (Honeyman, 1990; Magdoff, 1991). As an organic source of nutrients, manure is seen as preferable to commercial fertilizers from the viewpoint of production and environmental protection. However, as swine operations become highly specialized, they rely less on farm-grown feeds. Some farmers now view crops as a sink for the nutrients in manure rather than as a source of feed to be recycled back into the livestock operation. From a water quality perspective, less land application of manure means reduced risk of water contamination.

Among university researchers and extension specialists, discussion of manure management has focused on land application decisions. Although manure and various livestock products are produced jointly, economic research into livestock feeding and marketing decisions generally has ignored the value of manure (Chavas et. al, 1985; Skewes, 1986; Brown and Johnson, 1992). The goal of this paper is to outline a manure management "system" that acknowledges a broader perspective, viewing manure management as a system of interrelated decisions. This approach can determine the impact of the production environment on incentives to "waste" manure nutrients, by applying them to a crop sink, or to "want" them for recycling. "Production environment" is the combination of available technology, economic incentives, local physical conditions, and public policies facing producers. A complete understanding of how the production environment affects manure management will help policymakers design more effective and meaningful policies.

North Carolina and Iowa offer contrasting production environments that illustrate the important points of the paper. They represent two extremes in the "waste not" – "want not" continuum. Midwest operations, such as those in Iowa, tend to rely on land application to recycle manure nutrients. North Carolina farms generally use anaerobic lagoons to treat collected manure, thus reducing nutrients through biological activity. North Carolinians do not want the nutrients and therefore do not emphasize recycling them.

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Manure Management Decisions

Manure can be managed at four levels: production, treatment, transport, or crop selection (if residual nutrients are to be land-applied). Fig. 1 illustrates how the four levels are linked into a system. Decisions made at one level affect subsequent decisions at other levels. Assuming a producer wants to maximize whole-farm income implies a combination of decisions. Thus, the value of the manure is not simply the value of the commercial fertilizer it replaces. It also depends on crop prices, costs of treatment and transport, and the total amount of manure produced. The discussion below outlines how an array of considerations beyond simply nutrient content should enter a manure management plan.

Production decisions

Economic theory suggests that swine production decisions should depend on the joint value of pork and the manure that is produced. That is, producing meat yields manure. If net returns to the last unit of manure adds to whole farm income, a greater volume of meat and manure is likely to be produced. Alternatively, if returns from manure disposal are negative, that is, if disposal costs exceed nutrient benefits, this is an incentive to reduce meat production and therefore the amount of manure produced. Several types of herd decisions affect the nutrient concentration and total quantity of manure produced. Liveweight production is determined jointly by herd size and market weight decisions. The link between herd size and total volume of manure produced is direct and clear. The link between manure volume and market weight is less obvious. For a given feeding program, extending a production cycle produces a heavier market hog. More manure is produced per market cycle of heavier hogs. To some extent this is offset by fewer cycles per year. However, net annual manure production increases as production cycles are extended to produce heavier animals (Roka, 1993).

Feed rations represent another subset of decisions that directly bear on manure and nutrient production (Honeyman, 1993). Phase feeding regimes and supplementation with synthetic amino acids and phytase enzymes improve the efficiency of feed conversion and lower the excretion of nutrients, particularly N and P. Manure with lower nutrient concentrations can be applied to cropland at a higher rate without violating guidelines for nutrient loading rate.

Treatment and storage

A manure collection facility serves the dual roles of storage and nutrient treatment. Storage enables the livestock operator to dispose of manure stocks when it is convenient and environmentally appropriate. The anticipated maximum storage period will in part determine the size of the collection facility. The desired level of treatment also affects the size of a collection facility and the required capital investment. In this paper, the treatment uses anaerobic and aerobic bacteria to stabilize organic compounds and reduce the nutrient concentration of the manure effluent. Treatment levels vary with facility design, from low decomposition with in-house pits to complete decomposition with composting. The Midwest Plan Service (MWPS, 1985) estimates that 15 to 30% of the N in raw manure is volatilized from anaerobic storage pits. Alternatively, anaerobic lagoons volatilize between 70 to 95% of the excreted N (MWPS, 1985). North Carolina research has shown that N volatilization is directly correlated with lagoon size (Safley, 1992). Climate and other regional variables affect treatment efficiency by influencing bacterial activity. Therefore, given two lagoons of equal size, the lagoon built in a warmer climate, for example, reduces nitrogen concentration by a greater amount (MWPS, 1985).

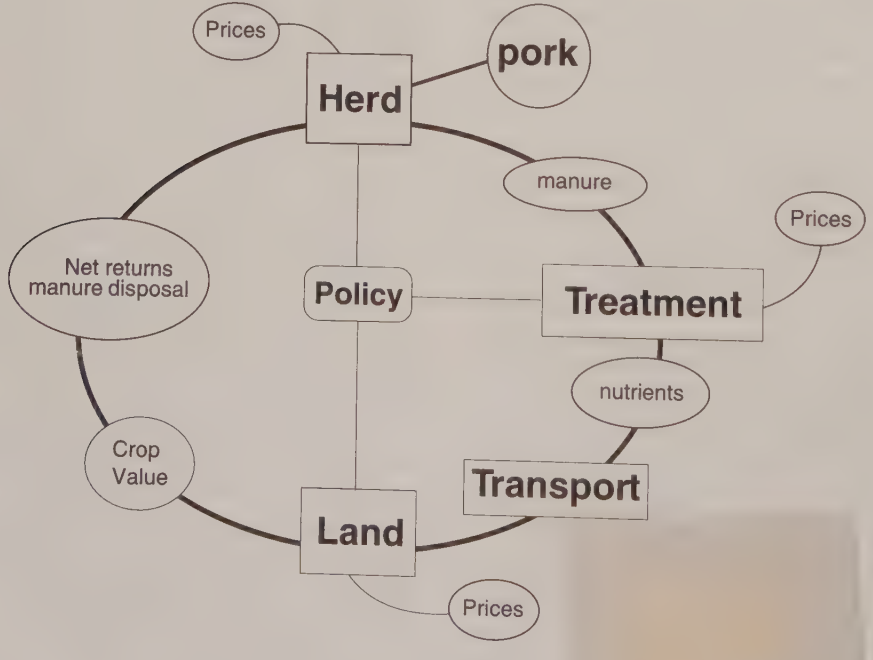

Figure 1. "Circle" of manure management decisions.

Transport

Transport involves delivering the manure effluent to the point of disposal. If manure is composted and sold as a soil amendment, transport cost is the cost of moving the bagged material from the composting facility to home garden centers. In a typical swine operation, the manure is transported to adjacent fields and applied to crops. The type of transport system depends on the type of material to be hauled, which in turn depends on the storage and treatment facility. Slurry, a semi-solid material, is removed from in-house storage pits using tank wagons pulled by tractors. The annualized costs of the tractor and tank wagon are fixed, and do not change with the amount of land receiving slurry. Assuming the application starts on fields nearest the collection facility, the cost of slurry application per acre increases with each additional load because of the increases in fuel and labor.

Alternatively, lagoon effluent is less than 10% solid and can be moved through conventional irrigation lines. The cost of irrigation differs from that of slurry application in that as the distance between field sites and

collection points increases, the fixed costs of pumps and irrigation lines become more important than the variable costs of fuel and labor. In contrast to the common result that transport costs per unit increase with greater volume, the total cost of irrigation in North Carolina was shown to decline over the first 120 acres of manure application (Cox, 1994).

Crop selection

Final disposal of manure nutrients involves crop selection, which is equivalent to selecting a per acre nutrient application rate. We assume that water quality concerns limit nutrient application rates to the crop's nutrient requirements, or agronomic rates. Crop nutrient demand in turn depends on the crop and expected yield. An important considration behind environmental policies is identifying which nutrient is the primary source of water quality problems. Restricting manure application rates to the agronomic nitrogen (N) rate implies that phosphorus (P) and potassium will be over-applied. Application rates based on agronomic P needs usually requires an N supplement and more area for manure disposal.

A producer considers two attributes when selecting a crop to receive manure effluent: profitability and ability to use nutrients. If the value of manure is negative, a livestock producer can increase profits by choosing as a waste sink a crop that is less profitable but that has a higher nutrient uptake. Higher nutrient demand reduces the level of treatment and reduces transport costs, thus increasing nutrient recycling.

The "Systems" Approach: Iowa vs. North Carolina

Typical manure management differs between North Carolina and Iowa swine producers. In North Carolina, producers flush manure effluent into lagoons, where it is estimated that up to 95% of the N is volatilized into the atmosphere (Barker, 1991; Safley, 1992). The remaining nutrients are irrigated on coastal bermuda grass. Hay is harvested, although the market price in North Carolina for coastal bermuda hay often is very low or zero. The value of coastal bermuda hay to North Carolina swine producers is its ability to take up nutrients. N can be applied at up to 325 lb/A (Zublena, 1991), reducing the area needed for effluent disposal.

Iowa producers, in contrast, collect manure as slurry, losing only 15 to 30% of the N (MWPS, 1985). It is hauled by tank wagon, with corn typically the receiving crop. Chase et al. (1991) found that Iowa farm profits increase when producers take full account of the nutrients in their manure and limit manure applications to the corn's nutrient requirements.

On the basis of their general manure handling practices, North Carolina producers can be characterized as nutrient minimizers (want not), while Iowa producers are nutrient conservers (waste not). These differences are reconcilable within the framework outlined above. In both states, corn is the most profitable livestock feed. However, the soils generally are more productive in Iowa than in North Carolina, meaning the Iowa producer forgoes more by growing hay instead of corn. In addition, Iowa's greater corn yields require more nutrients, increasing the savings in commercial fertilizer. Therefore, the Iowa producer has a greater incentive to use manure nutrients. Maintaining manure nutrients as slurry allows an Iowa producer to transport more nutrients per load, thus reducing transport costs.

Climate is another factor in a producer's production environment. North Carolina's reliance on lagoons is based in part on warmer winters. Average winter air temperatures of 41°F allow biological activity to continue throughout the winter. A lagoon in Iowa would have to be 30% larger than in North Carolina to achieve the same treatment level (MWPS, 1985). Lower treatment costs, coupled with poorer quality soil, provide the incentives for North Carolina producers to be nutrient minimizers.

Policy Implications

Policy, the economy, and the local physical environment combine to form a production environment that determines how a producer will manage manure nutrients. The level of control that occurs through manure production, treatment, or land application affects policy objectives such as water quality, odor control, or resource conservation. A better understanding of these relationships will help policymakers design more effective policies.

Current public policy objectives in both North Carolina and Iowa focus on protecting or improving water quality by controlling land application of nutrients (Iowa Department of Natural Resources, 1992; Zublena, 1991). In North Carolina, the Cooperative Extension Service publishes recommended land application rates based on crop N utilization rates (Zublena, 1991). The Iowa Division of Natural Resources recommends that total N available per acre should never exceed 400 lb/yr, with an average annual rate of 250 lb/yr. Also, P applications should not exceed the crop's uptake.

Both states have permitting processes that target larger operations and require construction of any manure collection facility to follow the technical specifications of the Natural Resources Conservation Service. Policy and education about manure management have not put manure in a systems context. Consequently, the Natural Resources Conservation Service offers a standardized approach when designing a collection facility. As more information is developed describing the relationship between facility design and nutrient concentrations, farm profitability may be improved by designing facilities that match a producer's specific needs.

Roka's (1993) management lessons for North Carolina and Iowa are presented in Table 1. In North Carolina, producers face low crop yields, low value of manure per acre, and low treatment costs. The opposite is true in Iowa. Therefore, producers in North Carolina use high treatment systems and irrigate the effluent on coastal bermuda grass, which takes up a large quantity of nutrients but is of low value. In Iowa, producers use a low treatment system and apply the waste to corn, a higher value crop than coastal bermuda or other grasses.

Two important policy lessons can be taken from these results. First, economics drives the producer to extremes. At one end of the spectrum, a producer uses very little treatment, thus preserving nutrients for land application. At the other end, the producer maximizes treatment, even choosing crops primarily for their ability to take up nutrients. One producer is a waste nutrient user, the other is a waste nutrient reducer. The policy implication is that policies will be more effective if they take account of the production environment. This systems approach shows that there are more

Table 1. Manure management lessons based on Roka's (1993) economic optimization.

	Iowa	N. Carolina
Production Environment		
Yield	high	low
Manure value	high	low
Climate	cold	warm
Treatment cost	high	low
Management Systems		
N losses	low	high
Level of treatment	low	high
Transportation method	haul slurry	irrigate from lagoons
Receiving crop	corn	bermuda grass

opportunities to manage the waste than simply regulating application rates, as is common today.

Second, policies affect choices by changing the production environment. Relevant policies include education, taxes on nutrients, restrictions on nutrient loading, and subsidies to adopt certain technologies. Policies will be effective if they account for the linkage between the policy target, such as ground water quality, and the production environment where the policy is to be implemented. Present manure management policies rely on land application restrictions, but manure can be managed in various ways for a variety of objectives. For example, if production is occurring in an area that is near a body of surface water that is easily polluted, the objective may be to reduce land application and increase treatment. An important policy question is the cost of changing the production environment to make treatment more profitable, and the best means to accomplish it. Should the state require larger lagoons, lower the allowable application rate, or subsidize treatment? Any of these would accomplish the water quality objective but how much they cost and who bears the cost will differ significantly.

Conclusions

Policy and education about waste management have not emphasized a systems context. Our research shows that producers range from nutrient minimizers to nutrient maximizers, that producer incentives may be uniform within but not between areas, and that a system includes many decision points to control pollution. We believe that the current policies that focus on land application are too narrow, limiting a grower's flexibility to exercise efficient controls and perhaps not even achieving the desired effects. We offer these suggestions:

- Make the policies more flexible and educate producers about all management options.
- Decide on policy goals, such as protecting surface water or recycling nutrients, and develop appropriate policies to address them, such as reducing effluent applications instead of increasing nutrient recycling.
- Evaluate the relative benefits and costs of a variety of policy instruments, such as: cost-shared land application, lagoon construction, and feeding regimes; regulations on collection, storage, or application methods; and taxes on inputs, lagoon size, or nutrient applications.
- Fund research to make lagoons more efficient, to alter swine rations or genetics, or to improve land application methods.

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Economics of widespread manure application to irrigated crops: Raw and composted feedlot manure in eastern Colorado

Erda Wang and Ed Sparling

Abstract. *We used linear programming to simulate adoption of manure disposal technologies in eastern Colorado. Manure, either raw or composted, is assumed to be applied to irrigated cropland within 20 miles of feedlots in five subregions of eastern Colorado. We constrained the application so that total N application is no more than the amount used by the crop. N, P and K contents are taken into account, but no benefits are assigned to organic matter or trace minerals and no costs are assigned to soil compaction, weed seed propagation, or inconvenience. Irrigated land within 10 miles of feedlots can easily absorb all manure generated under this scenario. Manure is found to be an economical substitute for chemical fertilizers, assuming N content to be at least 50% that of fresh manure. Composted manure is either more or less profitable than raw manure, depending on its N content. Hauling costs are lower for compost, but composting costs are between $1 and $2 per finished ton. The model does not allow for mixed application of compost and chemical fertilizers, which would increase the value of compost significantly. A feedlot waste sector that composted all feedlot manure in eastern Colorado is predicted to create between 80 and 200 additional jobs.*

Key words: beef cattle, composting, linear programming

Irrigated agriculture in eastern Colorado is dominated by the cattle feeding industry. Feedlots are interspersed with irrigated cropland, and feedlot manure often is applied to nearby cropland. At other feedlots, manure accumulates in large piles and then is hauled to landfills. There is both circumstantial and scientific evidence implicating feedlot manure as a source of water pollution. A possible remedy is to limit manure application to agronomic rates. Another partial remedy is to stabilize nutrients through composting. Such proposals prompt several questions:

- Is there enough cropland within an economically feasible hauling distance of feedlots to take all manure when applied at agronomic rates?
- Under these circumstances, will feedlot manure be an economically profitable substitute for chemical fertilizer?
- Under what circumstances is composting more profitable than applying raw manure?
- What economic effects would such strategies have on the feedlot, cropping and agrichemical sectors and on the regional economy?

This paper examines these questions with a spatial equilibrium linear programming model.

Important Assumptions and Limitations of This Study

A good explanation of this modeling technique, which is used extensively in agricultural economics, is given by Hazell and Norton (1986). A clear statement of the limitations of our model will help convey the sense in which it answers the questions listed above. A basic premise is that production coefficients can be derived from representative farm budgets. Farm budgets from which our model is derived are found in Dalsted et al. (1990). Our coefficients for feedlots are adapted from Madsen and Gee (1986).

General limitations of this type of optimization model include the tacit assumptions that markets are competitive (without monopoly power), that production resources are uniform and substitutable, and that economic entities (firms) can be aggregated and treated like a single decision-maker that tries to maximize its total profit. This last assumption may seem implausible to noneconomists. However, the idea is consistent with the widespread notion that competitive markets allocate resources as though guided by an "invisible hand" that seeks overall efficiency.

Other limitations arise from the failure to include important production alternatives and to identify accurately all limiting resources. Finally, failure to account accurately for costs and benefits may distort the results. We first discuss how these limitations affect the current application.

Market power. We assume that commodity prices are determined outside the region, for example in the corn or the beef market. Prices of land, feedlot capacity, and corn silage are determined within the model. Arguably, large feedlots exercise

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some control over the price of silage, since silage cannot be transported far. However, silage land also can be used to grow corn for grain, barley, hay and other crops. Therefore, large feedlots must pay a high enough price for silage to compete with those crops, and it is unlikely they exercise significant monopsony power in that market.

Production alternatives. The main irrigated crops grown in eastern Colorado are livestock feeds, especially corn grain, corn silage and hay. Some barley, sugar beets, and wheat also are grown, but they are insignificant compared with livestock feeds, and are ignored in the model.

Dryland crops are important in these regions, and some feedlot manure could be used on them. Because the model does not consider this alternative, its results may be distorted. We reasoned that most irrigated cropland is near feedlots. Therefore, it would cost more to transport manure to dryland crops than to irrigated cropland. Still, this assumption understates how much land is available to receive manure.

Resource availability. The amount of irrigated cropland in each subregion is stable. Since new irrigated land would require a significant investment in equipment or water rights, the amount of irrigated land is unlikely to change drastically in the future. We also treat feedlot capacity as fixed, an appropriate assumption for computing short-term results, but the results show which subregions are most likely to expand their feedlot capacity. Water is another resource that may eventually be limiting, but over the next decade, water supplies are predictable.

Estimated costs and benefits. In a model of this type, only costs and benefits that affect the profits of relevant decisionmakers are important for explaining market behavior. Failure to include any costs or benefits that are internal to the economic entity can cause distortions. When manure is used as a fertilizer, weed seeds and soil compaction often are mentioned as real costs. However, they are not reflected in the model, which therefore underestimates the cost of using manure. Another problem is uncertainty in the nutrient content of manure, particularly nitrogen (N). Accordingly, we used several values for the fraction of N stabilized by composting to determine the sensitivity of model.

In contrast, real costs and benefits that accrue outside the accounts of the economic entities do not affect economic behavior. In economic parlance, these are "externalities," and they are important from the public's perspective. An example is the cost of water pollution. Only N use is restricted in this model. If other nutrients like phosphorous (P) and potassium (K) are applied beyond the land's capacity to absorb them, the model ignores a cost that is significant for the public.

Aggregation of economic entities. In a model that treats all resources as though they are owned by a single decisionmaker, it often is impossible to tell how changes in costs or benefits are shared among the corresponding firms, including feedlot owners, farmers, and local agricultural service firms. However, if resources are owned by various groups of firms, changes in shadow prices from one version of the model to another can suggest which firms have the advantage in the distribution of revenues or costs. Thus, if the simulation suggests shadow prices on irrigated land will go up, we can guess that farmers will share in the bounty. If the shadow price on feedlot capacity go up, we can guess that feedlots will gain.

The Regional Setting and the Spatial Definition of Model

Eastern Colorado is part of the arid High Plains. The wheat-fallow system predominates on the six million acres of rainfed crops. Interspersed with wheat-fallow is extensive irrigation from two rivers and a large deposit of fossil groundwater. Of 1.5 million irrigated acres, about 800 thousand acres are in feed corn and about 600 thousand acres in silage or hay, most of which are consumed by the region's beef feedlots. The size of the eastern Colorado beef feedlot industry is shown by the fact that the region is a corn deficit region (Spencer and Rhodd, 1991). Net imports were 27.3 million bushels during 1990, almost 20% of total consumption in the state. In 1989, more than two million cattle were fattened in eastern Colorado's feedlots (Colorado Agricultural Statistics Service, 1990).

Definition of five production nodes

Production of feed crops and fed beef was represented at five "nodes," corresponding to five geographical subregions of eastern Colorado. The model allowed hay and corn to be traded between nodes. Corn and hay also could be traded with two other states.

The *production* nodes corresponded to groups of counties as follows:

Two on the South Platte River:

I: Upper South Platte Valley (Larimer, Boulder, Weld, Adams)

II: Lower South Platte Valley (Morgan, Logan, Sedgwick, and Phillips)

Two on the Arkansas River:

IV: Upper Arkansas River Valley (Pueblo, Crowley, and Otero)

V: Lower Arkansas River Valley (Bent, Prowers, and Baca)

One between:

III: High Plains (Yuma, Washington, Kit Carson, and Cheyenne)

Additional *import-export* nodes were: VI: Nebraska and VII: Kansas. Fig. 1 is a map of the modeled region. Subregions are also called "nodes."

Linear programming model of internode trade

Each node is modeled as an economic unit; when these are solved simultaneously, shadow prices or opportunity costs are developed for each resource and each commodity involved in production. If commodities can be moved between nodes, then a larger model can be built to solve the production problem in each node while simultaneously determining the optimal trading pattern between nodes. In this model, two commodities could be traded: feed corn and hay. We assumed that land, feedlot capacity and water were fixed in location.

The complete model can be visualized as a block diagonal matrix, where blocks represent production nodes and where activities connecting blocks are the 30 trading activities we consider economically plausible. Each of the five production nodes has similar matrix structure, but different resource availability and productivities. Each node had 25 crop and beef production activities (columns) and 36 constraints (rows) representing resources, commodities, and purchased inputs. The complete model had more than 200 columns and 180 rows. Construction of the nodes is explained below.

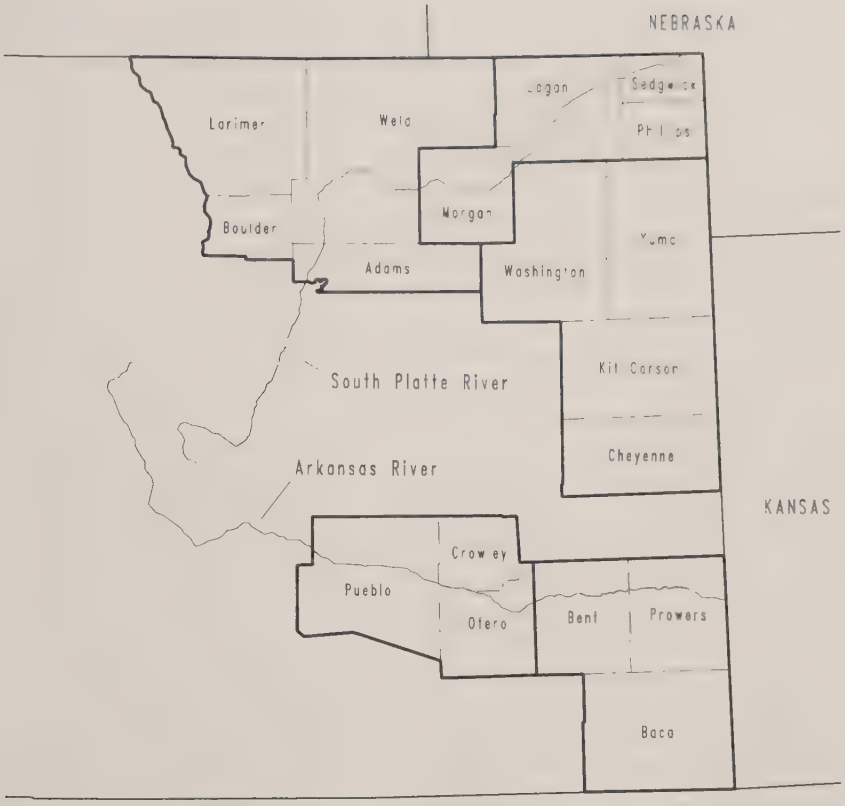

Figure 1. Map of the Modeling Region.

fertilizer. Cattle feeding activities require feedlot capacity and animal feed, and produce manure. Two models were built for each node: a base model with no provisions for disposal of feedlot manure, and a constrained model in which feedlot manure must be applied on irrigated cropland. For feed grains, the application rate could not exceed the N requirement. Irrigated hay was restricted to applications prescribed by Cooperative Extension.

Two versions of the constrained model were specified: raw feedlot manure could be applied directly, or it could be composted first at the feedlot. Table 3 presents the direct costs of using raw manure and compost. The costs of using raw manure only include handling at the feedlot, hauling, and spreading. Compost costs include these plus the cost of large-scale aerobic composting at the feedlot (Table 3). (Because composting reduces moisture content, one ton of compost is bulkier than one ton of manure, and hence is more expensive to handle.) The model does not specify who pays the cost of hauling and composting. Economic theory and common sense suggest that if the operation is profitable costs will be split so that all parties will benefit.

Modeling production within nodes

Feedlot Capacities. Table 1 shows the feedlot capacity associated with each production node. Feeding at each node could reach but not exceed that capacity. This is an intermediate-run model: cropping patterns and numbers of cattle fed can be changed, but the model does not allow investment in additional feedlot capacity or switching land between rainfed and irrigated.

Irrigated Land. Using maps of feedlot and crop location within each node, we divided each node's irrigated cropland according to its distance from the nearest feedlot, as shown in Table 2. In estimating hauling costs, we assumed that irrigated land was uniformly distributed around the feedlot. This results in an average distance of 7 miles for land less than 10 miles away, and 16 miles for land between 10 and 20 miles away. Since hauling to land less than 20 miles away exhausted the supply of manure in every node, no hauling was included for more distant areas.

Production Activities. Within each node, cropping activities require land, water, and

Table 1. Feedlot capacity, irrigated crops and capacity to absorb manure, by node.

Node Number	Name	Feedlot capacity (million head)	Irrigated land (1,000 acres)	Capacity to absorb manure[1] (million head)
I	Upper South Platte R.	1.028	453.5	3.35
II	Lower South Platte R.	0.420	301.4	1.87
III	High Plains	0.265	378.0	1.57
IV	Upper Arkansas R.	0.32	115.2	0.52
V	Lower Arkansas R.	0.18	86.8	0.35

[1] Number of head from which manure can be applied on cropland within 10 miles of feedlots. Based on compost retaining 70% N, and 1990 cropping patterns. Lower retention increases the capacity of land to absorb compost or manure.

Table 2. Irrigated cropland (1,000 A) within three distances of feedlot in each node.

Node	≤10 miles	10–20 miles	>20 miles	Total
I	188.0	251.7	13.6	453.5
II	93.4	144.7	63.3	301.4
III	73.0	248.4	56.7	378.0
IV	44.7	51.5	19.0	115.2
V	24.3	60.2	2.3	86.8

Sources: Colorado Land Use Commission, 1974; U.S. Dept of Commerce, 1989; Colorado Agricultural Statistics Service, 1990; Colorado Cattle Feeders Association, 1991.

Table 3. Cost of using manure and compost. ($/T)

Activities	Manure	Compost
Collecting, piling, loading	1.50	1.50
Processing	—	2.00
Hauling & spreading (mi)		
5	1.50	1.75
10	2.00	2.50
15	2.50	3.25
20	3.00	4.00

Compost hauling cost estimated by May and Tepfer, 1992.

Fertilizer value of manure and compost

N lost from manure is thought to be part of the water pollution problem associated with feedlots: nitrate is water soluble and is easily leached from manure piles before they are spread on crops. The nutrient content of beef cattle manure varies even from the same animal, particularly for N. However, any operational regulation of manure use on crops will require some assumed level of N in manure. Our model takes account only of the N, P, and K in manure and compost. Table 4 gives the assumed amount of N applied as raw or composted manure (based on May and Tepfer, 1992).

Each feedlot animal is assumed to excrete one ton of manure with 40% moisture, 1.1% N, 0.6% P, and 1.2% K (Overcash et al., 1983). We assumed that 50% of the N and 80% of the P and K are eventually available to crops if raw manure is applied (Follett and Croissant, 1990). The N, P, and K content of compost is adjusted by assuming that one ton of compost is produced from two tons of manure.

We assume that no P or K is lost in composting. The amount of N retained in compost is highly variable and is only partly determined by feedlot management. Manure application recommendations usually assume that 50% of the N in fresh manure is lost before it is applied to the crop. Timely manure collection from pens will reduce leaching and volatilization of N, while timely composting can increase the N stabilized in organic matter. In an extensive review of the agronomic literature, May (1993) discovered that we do not know how well composting conserves the N in manure. Given the importance of N both as a pollutant and a crop nutrient, this is a topic worthy of empirical research.

If most N in manure could be stabilized in organic matter through composting, less would mineralize and become available in the first year after application than if manure were applied raw. But if compost is applied consistently for several years, more N eventually would mineralize than from an equivalent quantity of raw manure that lost 50% of its N before application (May 1993). Because of uncertainty about how much N eventually is retained in compost, we solved the compost model using four levels of N retention: 40%, 50%, 60% and 70%.

Table 4. Manure or compost used on each irrigated acre, by crop and node.

Node	Crop	Yield/A	Raw Manure[1] (T/Acre)	Compost[2] (T/Acre)	N Used[3] (lb/A)
I	Corn grain (bu)	144	18	6.3	200
	Silage (T)	23.5	17	5.8	180
II	Corn grain (bu)	144	18	6.3	200
	Silage (T)	23.5	17	5.8	180
III	Corn grain (bu)	150.5	20	6.9	220
	Silage (T)	20	15	5.3	165
IV	Corn grain (bu)	135	17	5.9	180
	Silage (T)	17	14	5.0	155
V	Corn grain (bu)	135	17	5.9	180
	Silage (T)	17	14	5.0	155

[1] Each ton of manure contains 11 lb of N that eventually is available.
[2] Each ton of compost contains between 40% and 70% of the N from two tons of fresh manure. These application rates correspond to 70% retention.
[3] Recommendations from Colorado State Cooperative Extension (Dalsted et al., 1990).

The assumption that a consistent rate of manure application leads to a steady state of mineralized N is convenient for modeling purposes. However, this does not allow us to analyze the transition to this steady state. Another question is how to vary the application when crops are grown in rotation. Meaningful answers to these questions require a better knowledge of rates of mineralization of organic matter than is currently available.

The current recommended manure application rate per acre of irrigated alfalfa is 6 tons (Follet and Croissant, 1990). This would be sufficient to mineralize about 33 lb of N (May 1993). We assume that manure is applied to alfalfa at this rate. Compost application is adjusted according to the assumed rate of N retention. With 70% N retention, P would be too low. However, if alfalfa is rotated with corn, we can assume that surplus P and K from corn cropping would be available to alfalfa.

This is a weak assumption, however. Surplus P and K could become pollutants if corn for grain or silage do not consume the P and K from manure/compost. A possible solution would be to apply manure or compost with chemical fertilizers to avoid surpluses. A shortcoming of our study is that this alternative was not modeled.

Results

To establish a baseline, we simulated the cropping and feeding patterns of 1990. We then required that manure be applied to surrounding lands at the rates specified above. Feedlot operators had two alternatives: to spread raw manure or to compost it first. In the general model, composting dominated manure application, so that no results were generated for raw manure use. This result can be explained by the optimistic assumption regarding N retention in composted manure (70%), and by the fact that compost weighs much less than manure because water is lost during composting. These results are summarized in Tables 5 and 6.

The compost and manure alternatives were then incorporated into separate models, with four different assumed rates of N retention in composted manure. Table 7 reflects the results of changing the N retention assumption for the compost model.

Table 5. Comparisons of model results.

	Model		
	Base	Compost[1]	Manure[2]
	Fertilizer Materials (thou. tons)		
Compost/manure	0	1,107	2,305
Chemical fertilizer	93.6	81.2	83.7
	Costs and Returns ($ million)		
Total net return	188.6	191.6	190.2
Chemical fertilizer cost	52.8	43.2	46.7
Compost/manure cost	0	6.5	4.5
Total fertilizer cost	52.8	49.7	51.2
Savings compared with base[3]	—	3.0	1.6

[1] Assumes 70% retention of N.
[2] Assumes 50% retention of N.
[3] Computed from unrounded details.

Table 6. Comparison of feedlot shadow prices ($/head and % of base).[1]

	Model		
Node	Base	Compost	Manure
I	4.02	4.41 (110%)	4.13 (102%)
II	7.69	9.27 (121%)	8.63 (112%)
III	7.26	9.16 (126%)	8.29 (114%)
IV	1.71	2.28 (133%)	1.93 (113%)
V	0.39	1.27 (325%)	1.29 (331%)

[1] Shadow price is the increase of total net revenue in the whole market if there is one more unit of feedlot capacity in the region.

Table 7. Subsidy to achieve full feedlot manure use for compost, by node and N content of compost.

	N in Compost (% of N in Fresh Manure)			
Node	40%	50%	60%	70%
	$/ton			
I	0.875	0.440	0.125	0
II	0.225	0	0	0
III	0	0	0	0
IV	0.975	0.375	0	0
V	0.225	0	0	0
	Total ($ thousand)			
I	451.4	227	64.5	0
II	78.9	0	0	0
III	0	0	0	0
IV	260.9	100.4	0	0
V	33.8	0	0	0

Is there enough irrigated cropland to absorb manure? The first question posed is easy to answer: Each region contains more than enough irrigated cropland to absorb feedlot manure at rates that do not exceed the crops' ability to use N. In each region, a 10-mile radius around feedlots contains enough irrigated land to absorb at least twice as much manure as was produced in 1990. The two regions most likely to grow, the Upper Platte (Node I) and the High Plains (Node III) each can absorb three times the manure produced in 1990 without even using nearby dryland.

Is feedlot manure an economic substitute for fertilizer? This question is not so easily answered, and the answer must be qualified. Under the most optimistic assumption regarding N retention, the compost use model generates a net revenue (profit above operating costs) of $192 million. This is an increase of more than 1.5% from the $189 million generated in the base model. A surprising result is that the raw manure model used all manure available in every node, while showing a gain of net revenue of about 0.75% above the base model.

In this model, raw manure is assumed to retain 50% of its N. If N retention with composting falls to 60%, not all the manure would be used in the Upper Platte River Valley (Node I) without some additional economic incentive. More than 70% of the manure was left over, and a subsidy of $0.125/ton would be needed to make compost competitive with chemical fertilizer (Table 7). Such a subsidy would have to be paid for all farmers. The total cost would be about $63,000, paid on the 500,000+ tons of compost that resulted from one million tons of raw manure. We did similar calculations for each of the five regions under the four N assumptions (Table 7). In three of the five regions, all manure would be used at the 50% assumption, and in the High Plains Region (Node III), manure would be exhausted even assuming 40% N retention. The subsidy never exceeds $0.90/ton. Note that this cost is well below the $2/ton that some feedlots were paying to haul manure away (R.G. Hallock, Extension Development Specialist, Pueblo, Colorado, private communication, Sept., 1994).

Under what circumstances does compost dominate raw manure? This model takes account of hauling and processing costs, but not weed seeds or soil compaction. Within the limits of our model, compost's ability to retain N in manure will have a significant effect in the economic value of composting.

What will be the effects on farmers, feedlots, fertilizer distributors and regional employment? Our model does not allow us to predict accurately who benefits most from

widespread use of feedlot manure as a soil amendment. It does suggest that both feedlots and farms would benefit, since shadow prices on both land and feedlots increased (Table 6).

If manure or compost is substituted for chemical fertilizers, what will happen to fertilizer suppliers? First, the total reduction in chemical fertilizer use would be about 12% (Table 5). Moreover, fertilizer distributors probably could benefit by becoming distributors of manure/compost. Hauling and spreading manure would require local labor and capital equipment. If services such as chemical analysis of compost were involved, the distributors would be likely candidates to supply them. Some eastern Colorado firms already are specializing in large-scale composting of feedlot manure. Most of the composted manure is sold to nurseries and greenhouse operators. In one area, some movement toward a composting business has included a possible partnership between feedlots, a composting machine owner, and a fertilizer supplier. Such arrangements would create jobs and reduce the need to bring fertilizer into the region.

The model does not directly give the employment effects of such a change, but the major costs in using compost/manure are labor and local capital. Consequently, there would be positive direct employment effects from substituting manure/compost for chemicals brought into the region. Wang (1993) used a regional input-output model (McKean et al., 1982) to estimate direct plus indirect job creation from a composting sector in eastern Colorado. He estimated that between 0.08 and 0.2 jobs would be created per 1000 tons of compost manufactured and used. Extrapolating these multipliers to all manure from all eastern Colorado feedlots yields an additional 80 to 200 jobs.

Conclusions

These results suggest that feedlot manure can be an economically efficient substitute for chemical fertilizers. Indeed, extensive application of manure already is common near feedlots of eastern Colorado. Yet some Colorado feedlots haul their manure to landfills. The reasons for low demand for feedlot manure include weed seeds, soil compaction, inconvenience and odor. Since composting seems to improve manure in all these respects, it may be a partial solution to the feedlot waste problem. Problems remain, however, because of the apparently variable nutrient content of compost.

Is this study premature in view of the uncertainty of its outcomes? We believe it is not. First, the range of outcomes suggests that widespread composting of feedlot manure may be profitable for both farmers and feedlots in eastern Colorado. Second, the breadth of possible consequences suggests a need for agronomic research. The increasing number of farmers who wish to decrease their use of chemical fertilizer are demanding more reliable information about the agronomic value of feedlot manure. Another source of demand for this information is feedlots needing to dispose of manure in an environmentally sound way. Convergence of these interests suggests a direction for cooperative public-private research.

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EPA, USDA Coordinate Biocontrol Program For Colorado Potato Beetle

The EPA and USDA have formed a partnership with the National Potato Council, the New Jersey Department of Agriculture, private industry, and government and private institutions in Poland and the Czech Republic to control the Colorado potato beetle by introducing and demonstrating the effectiveness of the latest biocontrol technologies available in integrated pest management programs.

Economic analysis of an areawide program for biological control of the alfalfa weevil

J.M. White, P.G. Allen, L.J. Moffitt, and P.P. Kingsley

Abstract. *An areawide program for biological control of the alfalfa weevil showed expected economic benefits of $2.2 billion, expressed in present value terms. Alfalfa producers and consumers of livestock products are the main beneficiaries. The control program was highly successful, with a benefit/cost ratio of about 91. Not all areawide biological pest control programs will be as successful; a benefit-cost analysis like the one described here should be performed before areawide control is initiated to identify programs expected to provide economic benefits.*

Key words: cost-benefit analysis, alfalfa, pesticide use

Introduction

The public is concerned about the impacts of agricultural pesticide use on environmental resources and food and farm worker safety (see, for example, Center for Communication Dynamics, 1985). If popular media accounts are accurate, much of the public may regard use of biological pest control to manage agricultural pests as an appropriate alternative. Public policy officials are encouraging its use (Browner et al., 1993).

The economics of biological pest control will be critical to its role in agricultural production, and the need for economic evaluation of public biological control programs has been emphasized (Carlson, 1988). Results of economic evaluations probably will also be used in refining state and federal technology policy on biological pest control (see, for example, Simmonds, 1967).

This article presents the results of a market-level economic evaluation of an areawide biological control program for the alfalfa weevil (*Hypera postica* [Gyllenhal] [Coleoptera: Curculionidae]) in the United States. First we briefly describe the program and review related literature on the economics of pest control. The next section presents the important assumptions, provides sources of parameters used in calculations and the survey data underlying the results, and describes the methods used. We then present and discuss the results, and conclude by discussing some uncertainties and limitations in an analysis of this kind.

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The Biological Control Program for the Alfalfa Weevil

The alfalfa weevil is an especially serious pest of alfalfa (*Medicago sativa* L.) because it is widespread and generally occurs at a high level of infestation (White, 1989). It damages alfalfa production throughout the 48 contiguous states. Insecticides and cultural practices, mainly timing of harvest, are common means of managing it (see, for example, Armbrust and Gyrisco, 1975). Alfalfa can tolerate small amounts of damage; this observation suggested to researchers that biological control might be suitable for at least some of its insect pests, in particular the alfalfa weevil.

Explorations into the use of natural enemies for controlling the alfalfa weevil began during the 1950s. Following identification of several species of parasitic wasps, U.S. Department of Agriculture researchers established six of these species in eleven northeastern and mid-Atlantic states (Dysart and Day, 1976). Releases of natural enemies of the alfalfa weevil occurred on a large scale in the United States during the 1980s (White, 1989). By 1990, USDA scientists and others cooperating with them were releasing parasitic wasps to provide biological control of the alfalfa weevil over the entire continental United States (Bryan et al., 1993; Kingsley et al., 1993). Parasites either were mass-reared in the USDA/APHIS laboratory at Niles, Michigan or were collected as parasitized weevils by sweeping commercial alfalfa fields. Field personnel from APHIS located suitable fields for parasite release, received containers of parasites, and performed the actual releases. Fields considered suitable were established alfalfa fields that had not been sprayed with pesticides in the previous month nor would be sprayed in the next two years (Bryan et al., 1993).

In succeeding years, USDA scientists sampled fields for weevils and measured parasitization rate in the laboratory. If the introduction appeared unsuccessful it was repeated. Introduction of parasites in the South was unsuccessful in controlling alfalfa weevils, so insecticides remain the best control method there.

Two economic studies of areawide biological control of the alfalfa weevil indicate that it was successful. Zavaleta and Ruesink (1980) used simulation models to investigate the economic benefits of using a parasite to manage the alfalfa weevil in the eastern United States. Their approach provided average impacts per hectare from ten simulated production years, which then were extrapolated to the regional level. They estimated that biological control could save

alfalfa producers $44 million per year. Potential effects on the market price of hay were not incorporated in this study, since the simulation model indicated that biological control affected yields only slightly.

Day (1981) reported on the economics of the initial USDA parasite releases in eleven northeastern and mid-Atlantic states, which began during the 1950s. Survey data on fields not treated for alfalfa weevil because of introduced parasites were used to estimate annual producer savings, assuming that one annual application of insecticide was saved. In addition, producer benefits were compared with estimated program costs associated with the releases. Day estimated that biological control saved producers $8 million per year, or about eight times the cost of the releases.

Neither study incorporated market-level impacts or dynamic adjustments, since such an analysis was not feasible with the models used. For example, there was no attempt to include biological control expenditures or to reconcile them with future benefits through discounting. In addition, cropland adjustments anticipated because of changes in farm-level pest control costs could not be incorporated in the models.

The net effect of such limitations is unclear, though not accounting for a stream of benefits from biological control could seriously underestimate its value. As an example, we estimate that the introduction of biological control of alfalfa weevil in northern and western parts of the United States has saved producers about $25 million per year in pesticide costs. Using the method we describe below, total undiscounted benefits to all sectors of the economy are two to four times larger in most years. However, the saving in pesticide costs is an unreliable guide. Adoption by farmers of a cost-saving technical change such as biological control tends to increase total supply and reduce prices. Farmers can end up with a smaller aggregate profit. This pattern has been repeated many times in U.S. agriculture. The economic benefits of biological control should always be measured as the maximum amount the affected parties would be willing to pay for the control, not the amount actually paid. Only if we bring into the calculation the benefits for other parts of the economy, especially consumers, do we see a true picture of the overall economic impact. Sophisticated techniques have been developed for measuring the willingness to pay using only observed market transactions (see for example, Just et al., 1982).

We undertook the present study to learn the economic consequences of the more than $22 million spent by the USDA and state cooperators in the 1980s on areawide biological control of the alfalfa weevil. The economic success of one publicly financed biological pest control program does not mean that others necessarily will fare similarly, so that this kind of analysis should be done for similar large-scale programs under consideration (Reichelderfer, 1981). Such an *ex ante* analysis of a potential large-scale program might utilize expert opinion, laboratory experiments and small-scale field trials to develop some economic expectations to be used in deciding about implementing a large-scale program.

Data and Methods

Our market-level economic analysis of a national biological control program for the alfalfa weevil had five steps (White, 1989).

USDA-APHIS survey. We used regional survey data collected by USDA's Animal and Plant Health Inspection Service as part of the parasite release program to make inferences about alfalfa production before and after biological control of the alfalfa weevil was established. APHIS researchers pinpointed six locations across the United States. A region consisting of six areas was mapped around each location. Each region either fell within a state or occupied parts of adjoining states: Iowa-Missouri; Iowa-Illinois; Ohio; Pennsylvania-New Jersey (all surveyed for six years starting in 1981); Nebraska (added in 1983); North Carolina (added in 1985); and California-Oregon (added in 1987). Within each area, five alfalfa fields were sampled to determine infestation and parasitization rates, and the spraying practice in each field was noted. The survey used an initial questionnaire before parasite releases to collect information from cooperating farmers on the amount of land sprayed with each chemical. Surveying continued for up to six years after the first parasite releases. Table 1 shows the survey findings.

We combined the fraction of surveyed land that was sprayed before and after parasite introduction with published and proprietary information to get regional estimates (White, 1989). We combined the survey results with data on insecticide prices and the costs of scouting, custom operations, machinery, and labor to construct budgets for the variable costs of insect control in alfalfa production before and after parasite releases for different regions (Tables 2 through 5) as detailed in White

Table 1. Fraction of alfalfa acreage sprayed with insecticide.

State/Region	Before parasite releases	Year						
		1981	1982	1983	1984	1985	1986	1987
California	0.68	—	—	—	—	—	—	0.36
Iowa	0.22	0.18	0.17	0	0	0.04	0	0
Missouri	0.70	0.72	0.66	0.02	0	0	0	0
Illinois	0.24	0.26	0.07	0.11	0.05	0.18	0	0
Ohio	0.53	0.13	0	0.01	0.06	0.06	0.04	0.13
Pennsylvania	0.38	0	0.22	0.00	0	0.21	0	0
New Jersey	0.00	0.13	0.16	0.04	0	0.18	0.11	0.00
Nebraska	0.17	—	—	0.11	0.06	0	0	0.25
No. Carolina	0.82	—	—	—	—	0.90	—	0.90
Oregon	1.00	—	—	—	—	—	—	0.12
Corn Belt	0.43	0.32	0.26	0.01	0.02	0.04	0.02	0.06
Pacific	0.70	—	—	—	—	—	—	0.31

Source: USDA-APHIS unpublished survey (1988).
— indicates that data are unavailable.
Corn Belt consists of Indiana, Iowa, Missouri and Ohio. The Corn Belt state of Illinois is measured separately in the simulation program. Pacific consists of California, Oregon and Washington.

Table 2. Variable costs of insect control for alfalfa, Pacific Region.[1]

	Area (A)	Appl. rate (lb a.i./A)	Cost per A or per lb ($)	Total Cost ($)
Before Parasite Release				
Area surveyed	6,647			
Area sprayed	4,554			
Variable costs				
Insecticide				
Malathion	2,027	1.0	2.24	4,540
Carbofuran	2,527	0.5	10.59	13,380
Machine fuel, lube and repairs	2,792		0.62	1.731
Custom operations	1,762		7.00	12,334
Labor	2,792		0.33	921
Total variable costs				32,907
Variable costs/A				4.95
After Parasite Release (1987)				
Area surveyed	837			
Area sprayed	263			
Variable costs				
Insecticide				
Carbofuran	244	0.5	10.59	1,292
Chlorpyrifos	19	0.25	7.50	36
Machine fuel, lube and repairs	160		0.62	99
Custom operations	103		7.00	721
Labor	160		0.39	62
Total variable costs				2,210
Variable costs/A				3.85

[1] Computed from USDA-APHIS data (unpublished survey, 1988).
California-Oregon survey data also used for the Mountain region (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming).

Table 3. Variable costs of insect control for alfalfa, Northern Plains.[1]

	Area (A)	Appl. rate (lb a.i./A)	Cost per A or per lb ($)	Total Cost ($)
Before Parasite Release				
Area surveyed	2,675			
Area sprayed	224			
Variable costs				
Insecticide				
Malathion	80	1.0	2.24	179
Carbofuran	84	0.5	10.59	445
Carbaryl	60	1.0	3.78	227
Machine fuel, lube and repairs	224		0.65	146
Labor	224		0.35	78
Total variable costs				1,455
Variable costs/A				0.54
After Parasite Release (1984)				
Area surveyed	634			
Area sprayed	35			
Variable costs				
Insecticide				
Carbaryl	35	1.0	3.78	132
Scouting	42		2.00	84
Machine fuel, lube and repairs	35		0.65	25
Labor	35		0.48	17
Total variable costs				256
Variable costs/A				0.40

[1] Computed from USDA-APHIS data (unpublished survey, 1988).
Northern Plains consists of Kansas, Nebraska, North Dakota and South Dakota. Figures are based on the Nebraska survey.

Table 4. Variable costs of insect control for alfalfa, Corn Belt.[1]

	Area (A)	Appl. rate (lb a.i./A)	Cost per A or per lb ($)	Total Cost ($)
Before Parasite Release				
Area surveyed	6,355			
Area sprayed	3,053			
Variable costs				
Insecticide				
Malathion	756	1.0	2.24	1,693
Diazinon	78	0.6	32.30	1,512
Methoxychlor	279	1.0	8.37	2,335
Carbofuran	1,050	0.5	10.59	5,560
Carbaryl	210	1.0	3.78	794
Methyl parathion	165	0.5	3.38	279
Parathion	50	0.25	2.34	29
Dimethoate	380	0.5	7.55	1,435
Methidathion	75	0.5	8.37	314
Scouting	100		3.00	300
Machine fuel, lube, repairs	2,650		0.55	1,457
Custom operations	403		7.00	2,821
Labor	2,650		0.27	715
Total variable costs				19,244
Variable costs/A				3.03
After Parasite Release (1983)				
Area surveyed	1,266			
Area sprayed	15			
Variable costs				
Insecticide				
Methyl parathion	15	0.5	3.38	25
Scouting	1		3.00	3
Machine fuel, lube and repairs	13		0.55	7
Custom operations	2		7.00	14
Labor	13		0.36	5
Total variable costs				54
Variable costs/A				0.04

[1] Computed from USDA-APHIS data (unpublished survey, 1988).
These rates also used for the Lake States of Michigan, Minnesota and Wisconsin.

(1989). We assumed that fixed costs and variable costs other than for insect control were unchanged by the biological control program. Insecticide prices were national figures. Scouting and custom operations were based on responses to the survey. Machinery and labor costs were from separate USDA Cost of Production Surveys.

We did not develop changes in variable costs for four southern regions (USDA regions Southern Plains, Delta, Southeast, and Appalachia), under the assumption that because of the climate, controlling the alfalfa weevil would require continued insecticide treatments. These four regions account for approximately 5% of U.S. alfalfa acreage.

Econometric model. We used changes in variable costs as inputs to AGSIM, an econometric simulation model of United States agriculture developed to analyze the aggregate economic impacts of various agricultural strategies, particularly pest management (Taylor, 1987; 1993; 1994). We did not include changes in crop yield, because the simulation modeling of Zavaleta and Ruesink (1980) and the actual experiments by Day (1981) indicated that yield is negligibly affected. We used AGSIM to estimate the changes over time in production, domestic consumption, international trade, and other economic variables that could be attributed to reductions in variable costs from a national biological control program.

AGSIM consists of demand and supply equations for different regions, products, and uses of products, from which equilibrium production and price can be calculated. Time delays and linkages between commodities also are built into the model (see Taylor, 1993, for a diagrammatic depiction). The equations included in AGSIM were estimated from market data, usually by the method of least squares. When information on the biological control program for the alfalfa weevil is input to AGSIM, it estimates crop areas, the amount of each commodity going to each use (e.g., corn for food, feed, export, and stocks), prices, and other economic variables.

Consumers' and producers' maximum willingness to pay. We estimated producers' and consumers' maximum willingness to pay over time for national biological control using the econometric model. Welfare changes were evaluated by a component of the AGSIM model. The willingness to pay concept applies equally well to individuals or to groups. AGSIM estimates aggregate

Table 5. Variable costs of insect control for alfalfa, Illinois.[1]

	Area (A)	Appl. rate (lb a.i./A)	Cost per A or per lb ($)	Total Cost ($)
Before Parasite Release				
Area surveyed	1,630			
Area sprayed	446			
Variable costs				
Insecticide				
Malathion	140	1.0	2.24	314
Diazinon	20	0.6	32.30	388
Carbofuran	155	0.5	10.59	821
Carbaryl	121	1.0	3.78	457
Scouting	210		3.25	682
Scouting	50		2.35	118
Machine fuel, lube and repairs	406		0.55	223
Custom operations	40		7.00	280
Labor	406		0.28	114
Total variable costs				3,397
Variable costs/A				2.08
After Parasite Release (1982)				
Area surveyed	324			
Area sprayed	23			
Variable costs				
Insecticide				
Carbaryl	8	1.0	3.78	30
Carbofuran[2]	15	0.5	10.59	79
Scouting	51		3.25	166
Machine fuel, lube and repairs	21		0.55	12
Custom operations	2		7.00	14
Labor	21		0.38	8
Total variable costs				309
Variable costs/A				0.95

[1] Computed from USDA-APHIS data (unpublished survey, 1988).
[2] The alfalfa actually was sprayed with Phosmet, but no application rate or price was available. Therefore, we used the modal chemical use for this region in the calculation.

maximum willingness to pay as revealed by consumer and producer market behavior reflected by the time series data on which the model is based. Following other theoretical and applied work, we take estimated maximum willingness to pay as a measure of benefits (see Just et al., 1982).

Program costs. We collected annual public expenditures specifically identified with the biological control program throughout its duration. Annual expenditures by USDA and its cooperators on this national biological control program were estimated in cooperation with USDA/APHIS. Private expenditures, such as those that might have been incurred by farmers, were negligible.

Present value analysis. We applied four different discount rates (0, 2, 4 and 8%) to the net benefit streams to calculate net present value. These rates span the range of real discount rates found in the literature. In addition, we evaluated the net present value of a stream of benefits assumed to continue indefinitely, using a 4% real discount rate. We regard this as the most appropriate computation for this problem.

Results

Table 6 shows the estimated annual economic benefits of the national biological control program for the alfalfa weevil for the period 1987-1996. According to these calculations, crop producers benefit, mainly from pest control cost savings that exceed reductions in revenues. However, livestock producers lose because cheaper hay leads to increased production, lower prices, and lower returns. This seemingly paradoxical result may occur whenever an industry produces products such as food, particularly milk, for which demand is relatively rigid and substitution of productive inputs is relatively easy. For example, feed rations may be altered readily to expand production, disproportionately reducing market prices and industry welfare. Farmers' profits decline; however, farmers suffer as landowners rather than as operators. For this reason, some economists refer to the changes in producers' welfare as "changes in economic rent." Finally, crop and livestock consumers are expected to gain because of lower livestock prices.

Table 7 shows the actual public expenditures on alfalfa weevil biological control. Program costs were recorded back to 1980 and continued to 1990. These costs are in current dollars, and must be converted to 1987 dollars (the base year for analysis) to adjust for inflation. Excluded from expenditures are the costs of fundamental research that made possible the specific research into alfalfa weevil parasitization.

Converted to 1987 dollars, benefits and costs were combined to give an annual

Table 6. Estimated value of economic benefits from biological control of the alfalfa weevil (million 1987 $).[1]

	Domestic Crop Consumers[2]	Foreign Crop Consumers	Crop Producers	Livestock Producers	Consumers[3]	Livestock Producers
1987	33.71	0.58	29.05	0	0	63.34
1988	31.79	–0.32	32.89	–53.07	22.99	34.27
1989	28.16	–0.88	33.15	–47.89	6.51	19.04
1990	31.64	1.28	28.54	22.35	–26.62	57.19
1991	42.44	3.98	19.23	103.17	–59.76	109.06
1992	45.05	4.71	17.35	128.67	–67.24	128.54
1993	45.62	4.33	17.54	120.89	–60.05	128.33
1994	43.29	3.53	20.22	96.59	–48.42	115.21
1995	43.73	3.30	21.11	83.14	–41.97	109.32
1996	43.02	3.09	21.54	71.74	–37.72	101.68

[1] Benefits were estimated using the econometric model AGSIM.
[2] "Crop" includes corn, grain sorghum, barley, oats, wheat, soybeans, cotton, and all hay.
[3] "Livestock" includes beef, pork, chicken, milk, and veal.

Table 7. Annual expenditures of alfalfa weevil biological control program ($ million).[1]

	USDA			
	ARS	APHIS	Program Cooperators	Total
1980	1.0	.57	0	1.57
1981	0	1.07	0	1.07
1982	0	1.13	0	1.13
1983	0	1.19	1.89	3.07
1984	0	1.37	2.48	3.86
1985	0	1.31	2.22	3.52
1986	0	1.19	1.95	3.14
1987	0	0.94	1.37	2.31
1988	0	0.71	1.03	1.74
1989	0	0.39	0.52	0.91
1990	0	0.13	0.30	0.43

[1] USDA-APHIS.
[2] Total may differ from the sum of the details because of rounding.

stream of net benefits (Table 8). For national biological control of the alfalfa weevil, net benefits were negative from 1980 until 1986 and positive from 1987 until the end of the planning horizon in 1996. Because this calculation omits benefits expected beyond the planning horizon, it gives a very conservative estimate of the economic benefits of the program.

Finally, we compared the streams of annual benefits and of costs by converting them to their value in 1987, with future values discounted (or past values compounded) at a real annual rate of 0, 2, 4 or 8%. Detailed computations associated with a real discount rate of 4% are shown in the last three columns of Table 8. The benefit/cost ratio for each rate is shown in Table 9. The estimated benefit of an areawide program, $677 million (in 1987 dollars), is about 25 times the program cost at a 4% real rate of discount. If the benefits of biological control continue indefinitely instead of ending in 1996, as originally assumed, the benefit/cost ratio is 91 at a 4% real discount rate.

Discussion

Analysis of the economics of an areawide biological pest control program needs to look beyond program expenses, production costs saved, and changes in crop yield. Widespread implementation of such a program affects the price and output of the crop, of other crops that could be grown in its place, and of livestock that consume the affected crops. This study found that areawide biological control of the alfalfa weevil provided substantial economic benefits above costs in a market-level analysis. We consider this finding conservative, both because of how we estimated the market benefits and because we did not include the environmental benefits of reducing insecticide use.

Two particularly critical assumptions in this analysis are the discount rate and the duration of the benefits. Control of the alfalfa weevil by wasp parasites is expected to last forever. However, environmental changes, genetic mutation, or the appearance of new pests that can be controlled only by chemical sprays could end the program's effectiveness. The sooner this occurs, the closer the final benefits will come to those shown in Table 8.

The question of appropriate discount rate has no single answer on which economists can agree. The choice makes a big difference, especially for projects whose benefits exceed their costs only slightly. We present the details using a real rate of 4% because this is about the rate of return that lenders want on long-term government investments.

The results of economic evaluations of biological pest control programs such as this one will be used in refining public policy and funding of biological control programs. The evident success of this program does not necessarily mean that other areawide biological pest control programs will also be as successful. The method described here can be used with limited experimental data and expert judgment to predict the responses that would occur in a future large-scale biological control program. The predicted benefit/cost ratio and the distribution of benefits and costs among the different sectors of society will suggest to policymakers whether that control program should be implemented.

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Table 8. Expected costs and benefits of biological control of the alfalfa weevil (million 1987 $).

	Undiscounted			Present Value Factor	Discounted to 1987		
	Program Benefits	Program Costs	Net Benefits		Program Benefits	Program Costs	Net Benefits
1980	0	2.17	–2.17	1.315	0	2.85	–2.85
1981	0	1.34	–1.34	1.265	0	1.70	–1.70
1982	0	1.33	–1.33	1.217	0	1.62	–1.62
1983	0	3.50	–3.50	1.170	0	4.10	–4.10
1984	0	4.22	–4.22	1.125	0	4.75	–4.75
1985	0	3.71	–3.71	1.082	0	4.01	–4.01
1986	0	3.26	–3.26	1.04	0	3.39	–3.39
1987	63.34	2.31	61.03	1	63.34	2.31	61.03
1988	34.27	1.67	32.6	0.962	32.97	1.61	31.36
1989	19.04	0.83	18.21	0.925	17.61	0.77	16.84
1990	57.19	0.37	56.82	0.889	50.84	0.33	50.51
1991	109.06	0	109.06	0.855	93.25	0	93.25
1992	128.54	0	128.54	0.822	105.66	0	105.66
1993	128.33	0	128.33	0.790	101.38	0	101.38
1994	115.21	0	115.21	0.760	87.56	0	87.56
1995	109.32	0	109.32	0.731	79.91	0	79.91
1996	101.68	0	101.68	0.703	71.48	0	71.48
Total					704.00	27.43	676.57

Table 9. Benefits and costs of biological control under various assumptions.

Duration of Benefits	Real Discount Rate (%)	Benefits (million 1987 $)	Costs (million 1987 $)	Benefits/Costs
To 1996	0	841	24.7	35
	2	753	26.0	30
	4	677	27.4	26
	8	533	30.6	18
Indefinite	4	2,464	27.4	91

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Adopting multidisciplinary approaches to sustainable agriculture research: Potentials and pitfalls

C. Robert Stark, Jr.

Abstract. *Multidisciplinary approaches are being attempted by agricultural research units along with their traditional single discipline approaches. Although single discipline research will still be needed, multidisciplinary approaches present special advantages.*

The potential value of multidisciplinary approaches to sustainable agriculture research will be viewed differently by researchers with different perspectives. The participants in this symposium, all of whom were experienced sustainable agriculture researchers, identified five areas as keys for success. First, to capitalize fully on the opportunities it provides, there must be a justification for using a multidisciplinary approach for the specific research topic; while some projects work best with a multidisciplinary approach, others are best done within a single discipline. Second, everyone involved, including administrators, must invest time and money to establish communication between the disciplines. Third, careful attention must be given to forming and operating multidisciplinary teams effectively so that they generate shared benefits. Fourth, new sources of research funds will become available as agencies adopt multidisciplinary approaches, and revised systems will be required to administer those funds at the university or research unit level. Finally, major adjustments in the present systems for promotion, tenure and publication are necessary to properly measure and distribute credit.

Key words: multidisciplinary research, communication, teams, administration, research funding

Purpose and Approach

Sustainable agriculture emerged as a prominent issue during the 1980s. Publications such as Rodale's *Breaking New Ground* (1983), Jackson's *New Roots for Agriculture* (1980), and Sampson's *Farmland or Wasteland: A Time to Choose* (1981), stimulated researchers' interest in sustainable agriculture. But the correct approach in this research still is debated, particularly among those academic and governmental entities that bear the primary research charge. Opinions on multidisciplinary approaches for sustainable agriculture research vary with the individual researcher's perspective of the process. Therefore, it is important to understand other perspectives when evaluating this research approach.

To promote this understanding, a symposium of sustainable agriculture researchers from public, government, and university sectors was organized to share perspectives and identify the potentials and pitfalls of multidisciplinary research teams. The participants represented physical and social science disciplines, public organizations and cooperators, government funding and administrative agencies, and academic administrations (see Appendix). The primary objective was to bring together experienced individuals who had conducted sustainable agriculture research and could address key issues of the multidisciplinary approach from their perspective.

The panelists described their research experiences and their particular observations on the process. After discussion among all the panelists, the audience offered questions. The synopsis presented here does not attach specific quotations to individuals, nor does it necessarily represent a consensus. Rather, it tries to summarize the comments offered during the symposium to increase our understanding of the potentials and pitfalls of multidisciplinary research in sustainable agriculture.

Keys to Successful Multidisciplinary Research

Justification: Multidisciplinary vs. single discipline research

The first question is whether multidisciplinary research is necessary. Agricultural disciplines have evolved over hundreds of years by recurring divisions and consolidations. New disciplines emerged as researchers and scholars found that the existing disciplines were inadequate to address prevailing research issues. Old disciplines occasionally disappeared when their major research topics no longer were sufficiently prominent. But establishing a justification for multidisciplinary research

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This paper is a synopsis of a symposium on multidisciplinary research on sustainable agriculture conducted at the Southern Agricultural Economics Association Meetings, Nashville, Tennessee, on February 7, 1994.

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goes beyond the birth and death of single disciplines.

Whether sustainable agriculture should be studied through single discipline or multidisciplinary research depends on our perception of what sustainable agriculture should be. As Hutchinson (1990, p. xvi) has said, "A sustainable system must be both economically profitable and environmentally compatible." This suggests that sustainable agriculture research must include at least economics and the physical sciences. But some insist that solving today's agricultural problems will require cooperation by all disciplines. This may require that it include nonagricultural scientists and nonacademics. Some would suggest further that both single discipline and multidisciplinary research will be needed in the future, since each has a unique function that cannot be adequately filled by the other. This observation receives support when we recognize that most productive interdisciplinary researchers were first strong in their own disciplines. Keys for developing successful multidisciplinary teams may be found by looking at the partnerships that are already occurring across disciplines. Also, we must always remember that multidisciplinary research teams are still just a means, not an end. Both types of research are vital to the success of sustainable agriculture.

Communication

Often, multidisciplinary teams succeed or fail because of communication. All scientists use some technical terms and other jargon specific to their disciplines. For multidisciplinary teams to succeed, participants must invest the time to learn each discipline's language, perhaps through meetings and location visits to learn how the other disciplines operate. This process is necessary for each discipline to conduct its own analyses properly; the added knowledge, in turn, makes them more versatile and better equipped in their own discipline.

This communication can be fostered in many ways, including housing the disciplines together for multidisciplinary research. No matter how it develops, communication between disciplines is recognized as a vital component for successful multidisciplinary research in sustainable agriculture.

Formation, structure and operation

Assuming the multidisciplinary approach is justified and that researchers are both willing and able to communicate, how should multidisciplinary research teams be formed, structured and operated? Several possibilities exist. Often administrators will assemble a team to address an identified research need that has been funded. This type of team may function well for a while, but it may be difficult to sustain, especially after the initial funding has run out. Its members may have been brought together by an administrative invitation or perhaps "suggestion." Some of these teams become productive and develop a life on their own. But members more often have limited interest in these projects, so the team is likely to disband when problems develop.

A second way of building multidisciplinary teams is the "token member" process. An existing disciplinary team finds that the addition of a scientist from another discipline would be beneficial in securing funding or just making their proposal more appealing. But after the "token member" is added, if the other team members have a positive and receptive attitude, they may discover other mutual benefits from including the additional discipline.

The best way to create multidisciplinary research teams is to make it easy for members with shared interests to come together to address the research problem that has been identified. These teams are self-motivated to move forward with a positive, constructive attitude. Meetings of such teams seem to concentrate on research methods and results instead of management of project funds. The teams often are composed of scientists who have worked together on other topics and thus know what each team member can and will contribute.

Whatever the formation process, the structure and operation of multidisciplinary research teams is more complicated than that of single discipline research efforts. Multidisciplinary research increases the number of administrators who must be satisfied, often requires a new seniority order among researchers of equal academic rank, and can create accounting problems that many university business offices are not prepared to handle. Managing research associates who are simultaneously supported by multiple projects can be difficult for any research team. Single discipline groups within a team can feel pressure, real or perceived, to advance the interests of their own research associates, graduate students, or junior faculty members.

Perhaps the main difference in multidisciplinary research comes from the question being asked. The key research question should become "Does this result work?" instead of the present question "Is this result significantly different?" Multidisciplinary research tends to be problem-solving. By changing the key research question this way, we begin to develop longer-term goals that incorporate profitability as a top priority of farmers while recognizing that truly sustainable agriculture is long-term in nature. Our focus shifts from research for the sake of research to research with legitimate, straightforward applications. A side benefit will be that the image of agricultural research institutions will improve. The concern that society regards research institutions as self-serving is real and serious. The suggested shift in the key research question should reaffirm our present agricultural research system as the primary provider of useful, low-cost research results.

Multidisciplinary research teams provide opportunities that cannot be obtained through single discipline approaches and are the best way to bring diversity to sustainable agriculture research. They also offer the greatest potential for diversifying farm enterprises and introducing rotations that recouple animal and plant agriculture, a major contributor to sustainability. Furthermore, the multidisciplinary approach in sustainable agriculture research is likely the best way to incorporate the wealth of knowledge and resources held by the private sector and advocacy groups. Multidisciplinary teams represent an opportunity for sustainable agriculture scientists to initiate a change in the focus of all agricultural research, and for university administrators to provide the critical support necessary to implement these changes. The multidisciplinary approach also brings managers into the research process and lets producers help establish research priorities. New stakeholders are constantly getting involved in research, including consumers, environmentalists, and safety advocates. A multidisciplinary research approach can provide an avenue for these groups to become productively involved at every stage of the research.

Sources and administration of funding

Obtaining and handling research funds can be as difficult as forming and operating the multidisciplinary research team. The chances of getting initial funding for a sustainable agriculture research proposal may be enhanced when it is submitted by a multidisciplinary research team. Having a formal multidisciplinary research team seems to make research proposals more credible, and many funding agencies specifically encourage multidisciplinary proposals. But funds for such proposals are likely to originate from untraditional sources, and the problems of administering them can be greater.

Many of us have had experiences in which administering funds created problems for the whole project. Forming a multidisciplinary team can create discord when it is funded with money formerly dispersed among several faculty members' projects. Funding conflicts between disciplines can be avoided by spending the seed money primarily on equipment for the project instead of dividing it among disciplines. However, team meetings may then focus more on equipment purchases and the budget than on the research methods and results.

Existing university accounting systems may also pose a problem. Most systems are designed along disciplinary lines and cannot handle the multidisciplinary expenditures inherent in sustainable agricultural systems research. This may require that a team or staff member keep project accounts in addition to the university system.

Measuring and distributing credit

The final issue raised in multidisciplinary approaches to sustainable agriculture is how to measure and distribute credit for the effort expended and the results produced. This is obviously a more difficult problem with the inherently larger multidisciplinary research teams. However, several changes could reduce these conflicts.

First, team members should discuss at the start what output they expect from the research and how it will likely be publicized, such as through journal articles, extension bulletins, newspaper columns, and field day programs. It is seldom possible to anticipate the entire output, but experienced researchers usually can predict the major products. An early discussion of output often can avoid later arguments over who will be authors and the order of their names. Authorship ideally needs to be shared with all members of the team, but some publications may originate within only one discipline and therefore have only one or two authors. This may reduce authorship conflicts, but it does little to build the team concept wanted in multidisciplinary sustainable agriculture research.

Distribution of credit is especially critical for junior faculty members who are striving for promotions or tenure. Third or fourth authorship, which occurs more frequently in multidisciplinary publications, is generally accorded low value by review groups within individual disciplines. Also, scientists who conduct problem-solving types of research sometimes do not get the same respect as those who emphasize contributions to theory or quantitative methods. Low authorship position combined with a problem-solving research mode can create special problems for junior faculty members undergoing promotion or tenure reviews.

The second step to reduce conflicts would be to change disciplinary attitudes toward multidisciplinary research. This adjustment may be very difficult and must occur both on the university level and among professional publications. Land-grant universities were created to avoid "ivory towers," but the trend has been toward ever greater sophistication in quantitative methods and theory because of the perception that this makes the research more valid and "higher level." The real need is for administrators and faculty members to recognize that multidisciplinary team research provides the best opportunity to solve many of today's complex agricultural problems. Perhaps the solution is as simple as faculty talking more with graduate students about "the big picture" rather than concentrating so heavily on narrow issues. A narrow thesis topic may allow a PhD student to graduate sooner but do little to solve the real problems faced by our agricultural industry and the public. Another solution would be to change our dissertation and thesis design from the present lengthy, single volume style to a format involving multiple journal articles. Professionals read more journals than theses, so that dissemination of the information would be more timely and effective.

The attitudes that the editors of professional publications hold toward multidisciplinary research also must change. This can be achieved in two ways. One is to dedicate a portion of existing journals to problem-solving topics and producer perspectives. A more drastic step would be to create journals with a new focus. Existing journals sometimes choose not to publish submissions from multidisciplinary research teams even if some reviews are favorable, because the techniques tend not to be "cutting edge." Editors may reject multidisciplinary research articles out of fear that acceptance might lower the journal's prestige. Also, policies that limit the number of authors on a manuscript obviously discriminate against multidisciplinary research efforts.

Summary and Conclusions

Multidisciplinary approaches for sustainable agriculture research should be added to the present research programs of land-grant universities, government agencies, and other organizations participating in agricultural research. These approaches provide opportunities that cannot be obtained through single discipline approaches, but successful multidisciplinary research will require several changes in attitude and organization. Both single discipline and multidisciplinary research are needed, and both will continue to be needed. Faculty members, administrators and others must invest time and money to establish communication among disciplines if we are to solve the more comprehensive problems of the future. Careful attention must be given to how the multidisciplinary teams are formed, structured, and operated. New sources of funding and revised systems of administering research funds will be required to promote this approach successfully. Major adjustments are necessary, by both university personnel and publication outlets, in how credit for multidisciplinary research is measured and distributed.

The benefits of multidisciplinary research in sustainable agriculture far outweigh the costs. Sustainable agriculture research demands that scientists look at the big picture. Decades of research history have shown that disciplinary research alone can lead to isolated results that often contradict the findings of other disciplines. Economists who urged greater concentrations of livestock operations to achieve economies of scale failed to recognize the soil and water pollution

problems that would arise in waste disposal. Plant geneticists who developed corn varieties based on a single type of cytoplasm unknowingly put whole farm operations at risk in the Midwest when corn blight appeared. By creating multidisciplinary research teams that together search for answers, we can tap the synergy of shared knowledge that will propel us forward into a successful future in agriculture.

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INSTITUTE NEWS (Continued)

Wallace Institute Board Approves New Programs, Elects New Members

The Wallace Institute's Board, at its mid-year meeting in Carrington, N.D., approved two new programs and elected three new members who will start their terms in March, 1996. The board approved the Ward Sinclair Memorial Internship Program, established to honor the late Ward Sinclair, an organic farmer and Wallace Institute Board member.

The board also approved the Henry A. Wallace Annual Lecture on Science, Technology, and Public Policy, which will be launched on March 14, 1996. The annual lecture, to be given by a distinguished leader in agricultural science or policy, will honor the late Henry A. Wallace, a former Vice President of the United States and Secretary of Agriculture whose goal was to establish a viable farm economy and, at the same time, conserve the nation's natural resources. The lecture series will also draw attention to the challenges of U.S. agriculture and reach a broad audience with information about the importance of agriculture to this country.

The three new members elected to the Wallace Institute Board are:

Dr. Jill Shore Auburn, Associate Director, Sustainable Agriculture Research and Education Program, University of California, Davis; Regional Training Coordinator, Western Region USDA-SARE Program; and Chair, Information Directorate, World Sustainable Agriculture Association.

Christine (Cass) A. Peterson, farmer and owner of the Flickerville Mountain Farm and Groundhog Ranch in Dott, Pennsylvania; member, Board of Directors, Pennsylvania Association for Sustainable Agriculture; and member, Governor's Agricultural Advisory Committee to the Pennsylvania Department of Environmental Resources.

Thomas N. Urban, Senior Lecturer, Graduate School of Business Administration, Harvard University, and Chairman of the Board of Pioneer Hi-Bred International, Inc., where he was Chairman, President, and CEO from 1984 until summer, 1995; former member, President's Council — National Academy of Sciences; and former Mayor of the City of Des Moines, Iowa.

Applications For Ward Sinclair Internship Due March 1

Applications for the Ward Sinclair Memorial Internship Program, which will begin in 1996, are due on March 1, 1996. To honor the late Ward Sinclair — an organic farmer, a writer, and a member of the Wallace Institute's Board of Directors — the Wallace Institute will award one internship each year to a person desiring the "hands-on" experience of working on a farm that produces and direct-markets food, and with a public agency having responsibilities related to direct marketing. The internship will be for three to six months, from late spring to early winter.

Interns will spend approximately half their time working at the Flickerville Mountain Farm and Ground Hog Ranch in Dott, Pennsylvania, the farm established and managed by the late Ward Sinclair and Cass Peterson.

Trap cropping to manage the red sunflower seed weevil in oilseed sunflower

Gary J. Brewer and Gene Schmidt

Abstract. *The red sunflower seed weevil,* Smicronyx fulvus *LeConte, is a major pest of sunflower in North and South Dakota and Minnesota. Typically, insecticides are used to reduce oviposition and prevent economically damaging larval populations from developing. In a test of a reduced-pesticide alternative, we planted early maturing sunflower in the margins around commercial fields of oilseed sunflower. The margins flowered earlier than the field interiors and acted as a trap for the red sunflower seed weevil. They were treated with an insecticide while the trap rows were blooming and before the field interior began to flower. Conventional fields entirely treated with insecticide served as checks. We compared the trap and check fields with regard to yield, the fraction of larval-damaged seeds, and economic costs (insect damage and the cost of insecticide materials and application). Yield and larval damage of seeds were comparable between check and trap fields. However, the economic costs of weevil control in the check fields was greater than in the trap fields. Trap cropping is a recommended strategy for the red sunflower seed weevil, especially where economically damaging populations of the weevil are expected.*

Key words: *Smicronyx fulvus*, sunflower, *Helianthus annuus*

Introduction

Intercropping means planting more than one crop in a field to improve yield or quality of a least one crop by the interaction among crops. A trap crop is a special type of intercrop intended to lower pest damage by attracting the pest away from the main crop, thereby increasing yield (Vandermeer, 1989). Trap crops may be intercropped with the same or a different species. Risch et al. (1983) suggested that in intercropping, a reduced pest population will maximize yield when competition among the crops is low.

Trap cropping works because phytophagous insects have distinct preferences for certain plant species and growth stages (Hokkanen, 1991). It is usually considered in situations where conventional pest management is difficult or costly. Studies of the economic benefits of trap cropping typically report a 10 to 30% increase in net profit (Hokkanen, 1991). Profitability is increased if the trap crop and main crop are of the same species; they then can be harvested together, with the trap rows contributing to total yield. To be effective, a trap crop must be more attractive than the main crop during the critical period of pest colonization (Hokkanen, 1991).

The red sunflower seed weevil, *Smicronyx fulvus* LeConte (Coleoptera: Curculionidae), can cause severe economic loss in sunflower grown in North and South Dakota and Minnesota, the main sunflower production region (Oseto and Burr, 1990). The adults feed and deposit their eggs in the developing seeds (Brewer, 1991); the larvae are internal seed feeders (Oseto and Braness, 1979). If the population is high, economic damage occurs because of larval feeding (Oseto and Braness, 1980), which reduces seed weight and oil content (Peng and Brewer, 1995).

Insecticide applications are designed to reduce oviposition and prevent buildup of economically damaging larval populations. The weevil prefers to oviposit in plants that are shedding pollen and that have seeds of intermediate maturity (Brewer, 1991); they leave plants that no longer are producing pollen (Oseto and Braness, 1979). Because sunflower fields are rotated to other crops each season, overwintering weevils emerging from the soil must migrate to new fields. If they find a sunflower field that is partly in bloom, the blooming portion of the field may serve as a trap.

Sunflower fields are planted to either oilseed or confectionery hybrids (Carter, 1978). Confectionery sunflower produces an edible seed, so that the tolerance for insect injury is very low. Seeds of oilseed sunflower are processed to extract an oil, and therefore can tolerate more injury (McBride et al., 1992).

This study investigated whether strips of early-blooming sunflower along the edges of a field planted to a later variety could serve as a trap crop for the red sunflower seed weevil. Our objective was to determine how effective the trap was in concentrating adult weevils and in preventing the economic loss they cause.

Materials and Methods

Experimental design

Trials were done on commercial oilseed fields in North and South Dakota and Minnesota. Each farmer cooperator planted a pair of fields: one managed conventionally as a check, the other as a trap field. Between 1991 and 1993 we established trials on 19 farms, but collected data from only five of them. Some cooperators treated the entire trap field with insecticide because of concerns about high weevil populations or because the weather did not permit proper timing of sprays. All eight trials in 1993

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failed because of the unusually wet and cold season: three fields flooded, and weevil populations were too low in the others to allow testing.

The cooperator chose the fields to be planted as trap or check fields. The margins (trap rows) of the trap fields were planted to an early hybrid, with the planting date chosen so that the trap rows bloomed in late July to early August, after most weevils have emerged from the soil (Oseto and Korman, 1986). The interior of the trap field was planted to a later hybrid, with the planting date chosen so that it bloomed 7 to 10 days later than the trap rows. Because most cooperators had 8 or 16 row planters and because a single pass of an aerially applied insecticide covers about 16 rows, the trap was 16 rows wide. The insecticides used were either Asana XL at a rate of 0.04 to 0.06 kg/ha or 6-3 parathion-methyl parathion at a rate of 1.12 kg/ha.

The sampled fields ranged from 22 to 60 ha; trap rows occupied from 5.9% to 9.9% of the trap fields, with a mean of 7%. In calculating the trap area we assume rectangular fields, but in reality the borders were irregular because of sloughs and other obstructions. Thus, the actual field area devoted to trap edges was greater than the calculated value; in estimating the cost of insecticides in trap fields, we assume that the sprayed portion was 10% of the field.

Like the interiors of the trap fields, the check fields were planted to a later season hybrid (not necessarily the same one as in the interior of the paired trap field). The hybrids were selected by the individual cooperators. When most plants in the trap rows reached stage R5.4, with 40% of the head shedding pollen (Schneiter and Miller, 1981), each field was systematically sampled for weevils at 21 locations. At each location, we counted the number of adult weevils per capitula (head) on the 5 most mature plants and calculated the average for that location. In the trap fields, 12 of the sampling sites were in the trap borders (3 sites on each side, 8 rows in from the field margin), with the remaining 9 sites in the field interior. A similar sampling pattern was used in the check fields, except that each field was planted to a single hybrid.

To manage the adult weevils while they were still concentrated in the trap rows and before they dispersed to the field interior, the trap rows were treated with insecticide shortly before the field interior began to bloom. If weevil populations in either the trap field interior or the check field exceeded the economic threshold (Oseto and Braness, 1980), cooperators could treat them with insecticide.

At plant maturity, we took samples from two rows across each field, equidistant from the field ends. Each row was sampled at 9 equally spaced sites, for a total of 18 sites per field. We harvested 5.3 m of row at each sampling site. Heads were hand threshed and evaluated for yield and fraction of seed damaged by larval feeding.

Data analysis

We used analysis of variance with farms as blocks to compare trap and control fields regarding the number of weevils, crop yield and fraction of seeds damaged by larval feeding. To satisfy the assumption of homogeneity of variance, the fraction of seeds damaged was arcsine transformed.

The following procedure was used to determine the value of the loss (VL, in $/ha) attributable to larval feeding for each field in the five usable pairs. This procedure is needed because some growers planted different hybrids in the trap field interiors and the check fields, and because the fields in a pair were separated by 0.8 to 1.6 km. Therefore, the loss in value had to be estimated from the fraction of seeds infested in each field and the resulting reduction in seed weight and oil content.

Infested seeds weigh 0.042 g (W_I); uninfested seeds weigh 0.048 g (W_U) (Brewer, unpublished data). The fraction of infested seeds is designated as I; yield (Y) and yield loss (YL) are in kg/ha; the number of infested seeds (INF) is in seeds/ha. The calculations were done for seed prices (P) of $.017/kg and $0.25/kg, which represent the mean ± 1 S.D. for the period 1983 to 1992 (North Dakota Agric. Statistics, 1993).

The value lost from larval damage was calculated for each field as follows:

$$INF = Y \times I / [I \times W_I + (1-I) \times W_U] \quad (1)$$

$$YL = INF \times (W_U - W_I) \quad (2)$$

$$VL = (YL \times P) + (YL \times I \times 11.06 \times P \times 0.02) \quad (3)$$

Using data from one of the fields (I=10.3% and Y=1,267 kg/ha), for P=$0.17/kg, these equations lead to the following results: INF = 2.75×10^6, YL = 16.8, and VL = $2.92/ha.

In evaluating the economic costs of controlling the red sunflower seed weevil in check and trap fields, we first computed just the value of the yield loss (VL), as above. We then included the cost of insecticide (materials and application). The insecticide cost was assumed to be $18.53/ha in check fields, where the entire field was treated. In trap fields, only about 10% of the total area of each field was treated with insecticides. This was equivalent to a cost of $1.85/ha over the entire field.

Results

There were significantly more red sunflower seed weevils per head on plants in the trap rows (mean ± SD = 40.1±16.2) than on plants in the interiors of the trap fields (12.6±8.2; F=19.45; d.f.=1,4; p<0.01). The fraction of seed damaged by larval feeding was less in the check fields than in the trap fields (Table 1), but the difference was not significant (F=0.07; d.f.=1,4; p>0.10).

Mean yield in the trap fields was lower than in the check fields (Table 1), but the difference was not significant (F=0.56; d.f.=1,4; p>0.10). (Recall, however, that it is difficult to interpret a direct comparison of yields between the two kinds of fields because of spatial separation and differences in hybrids.)

For sunflower seed priced at $0.17/kg, the two kinds of fields did not differ significantly in economic loss per ha from reduced weight and oil content caused by larval feeding (trap fields: $3.59±2.37; check fields: $3.12±3.57; F=0.07; d.f.=1,4; p>0.10) (Fig. 1). However, when insecticide material and application costs were included, the economic cost of weevil control was $16.21/ha more in the check fields than the trap fields (F=78.18; d.f.=1,4; p<0.01). For sunflower seed at $0.25/kg, the economic cost when insecticide costs were considered was $15.99/ha higher in the check fields, again a significant difference (F=35.17; d.f.=1,4; p<0.01).

Discussion

The primary question in deciding if an alternative pest management strategy is effective is whether its economic benefit is at least as great as in the conventional practice. If not, its adoption is uncertain. Farmer adoption of any management strategy is

Table 1. Seed damaged by feeding of larvae of the red sunflower seed weevil and yields on five pairs of sunflower fields on different farms.

	Damaged seed, by farm (%)					Mean (S.D)
Trap	10.3	28.9	8.4	8.4	4.9	12.2 (9.6)
Check	31.8	12.8	2.5	2.8	2.8	10.5 (12.7)
	Yield, by farm (kg/ha)					Mean (SD)
Trap	1267	1109	1804	1361	1377	1383 (258)
Check	1210	1126	1470	1856	1856	1503 (346)

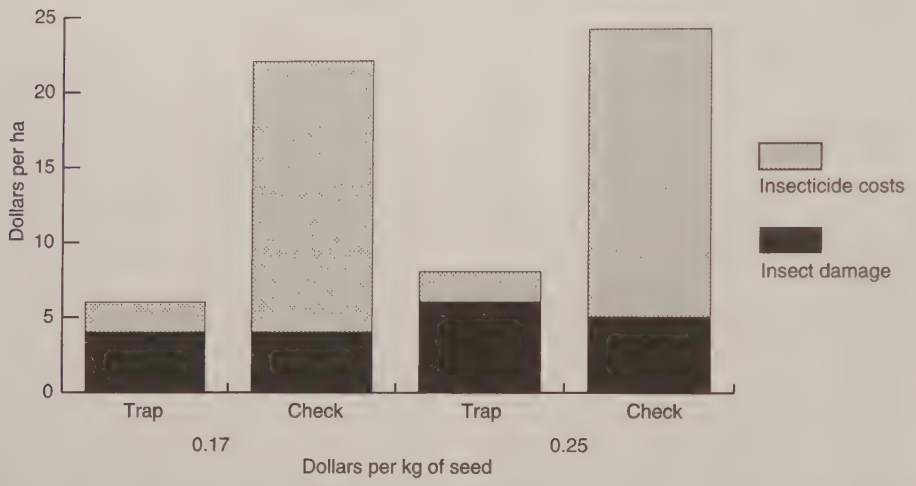

Figure 1. Reductions in economic return attributable to larval red sunflower seed weevil damage plus insecticide costs in check and trap fields. Values are the means for 5 pairs of fields, ranging from 22 to 60 ha, and are calculated at two different prices for sunflower seed.

decided by practical matters, including ease of use, cost of the alternative compared with conventional practice and, to a lesser extent, social and environmental impact.

Trap cropping to manage red sunflower seed weevils did not provide a yield advantage compared with whole-field insecticide treatment. However, it gave comparable yield protection at a lower cash cost, and presumably also a lower environmental cost. The cost benefit results from the large reduction in insecticide use in trap crop fields. A constraint to adoption is that it requires more intensive farmer management, primarily because of the two planting dates. Variable weather also was a limitation in some situations.

Dry conditions when the trap rows are planted delay germination until sufficient soil moisture is present. If there is no rain until after the interior rows are planted, plants in the trap rows and field interior may emerge together, and therefore flower at nearly the same time. Cool, wet conditions during vegetative growth may have the same result, again having no trap effect. When this happens, the field still can be treated conventionally, the only loss being the extra management involved in planting the trap crop.

An economically significant infestation may develop in the interior of a trap field after the trap rows have been treated. This may occur because some weevils are already in the interior and escape control when the trap rows are treated, or because other weevils migrate to the fields following treatment. Thus, field interiors should be monitored to detect the possible development of a high weevil population.

The economic benefit of trap cropping to manage the red sunflower seed weevil could be very large. Between 1983 and 1992, an average of 609 thousand ha per year was planted to oilseed sunflower in North Dakota (North Dakota Agric. Statistics, 1993). A survey of North Dakota aerial insecticide applicators showed that for the same 10-year period, an average of 252 thousand ha was treated per year with insecticide to control red sunflower seed weevils in oilseed and confection sunflower (Nelson, 1994). From 1983 to 1992, oilseed sunflower made up approximately 86% of the total area planted to sunflower in North Dakota. Trap cropping is not likely to be universally adopted, and traps will sometimes fail to develop, but if all oilseed sunflower in North Dakota is converted to trap fields, growers could save $4.2 million in a typical year.

In most situations, the difference between control costs for the red sunflower seed weevil in trap fields ($1.85/ha) and check fields ($18.53/ha) should make trap cropping advantageous. The traps were effective in concentrating adult weevils along the field edges, where they were easily controlled. Despite a slightly higher seed infestation rate and resulting loss of value in trap fields, trap fields are economically advantageous because the cost of treating trap fields is approximately 10% of conventional treatment. Trap cropping would be especially beneficial and is recommended in areas where economic populations of the red sunflower seed weevil are expected.

Acknowledgments. We thank all the cooperators, especially Mr. Daryl Rott, who provided the motivation for the project. This research was supported by grant LWF 62-016-02935 from the North Central Region Sustainable Agriculture Research and Education Program.

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UPCOMING EVENTS

January 19-21, Fifth Annual Conference and Trade Show of the Southern Sustainable Agriculture Working Group will be held in Lexington, KY; contact Community Farm Alliance, 200 Short St., #10, Berea, KY 40403; (606) 986-7400; or Keith Richards, Southern SAWG Conference, P.O. Box 324, Elkins, AR 72727; (501) 292-3714; e-mail HN3551@handsnet.org

January 24-27, 16th Annual Ecological Farming Conference will be held at the Asilomar Conference Center, Pacific Grove, CA; contact Committee for Sustainable Agriculture, P.O. Box 838, San Martin, CA 95046; (408) 778-7366.

January 24-27, "Today's Vision for Tomorrow's Agriculture," the annual meeting of the National Alliance of Independent Crop Consultants, will be held in Orlando, FL; contact NAICC, 752 E. Brookhaven Circle, $240, Memphis, TN 38117; (901) 683-9466.

January 26-28, Northern Plains Sustainable Agriculture Conference will be held in Mandan, N.D.; contact Sue Retka Schill, Northern Plains Sustainable Agriculture Society, HC5 Box 104, Langdon, N.D. 58249; (701) 256-2424; or Theresa Podoll, 9824 79th St. SE, Fullerton, N.D. 58441; (701) 883-4304.

January 26-27, "Organic Farming Comes of Age" will be held at the University of Guelph, Ontario, Canada; contact Hugh Martin, Ontario Ministry of Agriculture, Food and Rural Affairs, (519) 631-4700; or Tomas Nimmo, Canadian Organic Growers, (705) 344-0923.

January 27, 20th Anniversary Dinner of Canadian Organic Growers will be held at Conference Centre of Ignatius College, Guelph, Ontario, Canada; contact Anne Macey, (613) 259-2967.

January 31-February 4, Herb Business Winter Getaway Conference will be held in Albuquerque, New Mexico; contact Herb Growing & Marketing Network, P.O. Box 245, Silver Spring, PA 17575; (717) 393-3295.

February 2, Nebraska Sustainable Agriculture Society Western Area Conference will be held in Ogallala, NE; contact Jane Sooby, High Plains Ag Lab, 3257 Rd. 109, Sidney, NE 69162; (308)254-3918.

February 7-9, International Conference on Air Pollution from Agricultural Operations will be held in Kansas City, MO; contact Carole Seifert, Office of Extended and Continuing Education, Iowa State University, 102 Scheman, Ames, IA 50011; (515) 294-1400; e-mail x1seifer@exnet.iastate.edu

February 20-25, 1996 North American Farmers' Direct Marketing Conference will be held in Saratoga Springs, N.Y.; contact Monika Roth, Cornell Cooperative Extension, 615 Willow Ave., Ithaca, N.Y. 14850; (607) 272-2292; e-mail monika_roth@cce.cornell.edu

February 24, Nebraska Sustainable Agriculture Society Annual Meeting will be held in Columbus, NE; contact Cris Carusi, NSAS, P.O. Box 736, Hartington, NE 68739; (402) 254-2289.

February 26-27, "Urban Conservation 2000," a conference to evaluate urban erosion control and water management innovations, will be held in Seattle, WA; contact Soil and Water Conservation Society, 7515 Northeast Ankeny Road, Ankeny, IA 50021; (515) 289-2331 or 1-800-THE-SOIL.

February 27-March 2, Third National IPM Symposium/Workshop will be held in Washington, D.C.; contact Carol Kramer, USDA/ERS/NRED, 1301 New York Ave., NW, Washington, D.C. 20005; (202) 219-0453; e-mail ckramer@econ.ag.gov

February 29-March 2, Pacific Northwest Farm Direct Marketing Association Trade Show will be held in Eugene, OR; contact FDMA Trade Show, P.O. Box 3366, Salem, OR 97302; (503) 373-9650.

March 4-5, 19th Annual National Food Policy Conference will be held in Washington, D.C.; contact Public Voice, 1101 14th St., NW, #710, Washington, D.C. 20005; (202) 371-1840.

March 7-10, Bio Fach '96 will be held in Frankfurt, Germany; contact Sunder & Rottner, Von-Vollmar-Str.4, D-91154 Ruth, Germany; phone +49 (0) 9171-4011.

May 18-23, "Sixth International Symposium on Society and Resource Management: Social Behavior, Natural Resources, and the Environment" will be held at University Park, PA; contact ISSRM Symposium, Short Courses and Conferences, Pennsylvania State University, 306 Agricultural Administration Building, University Park, PA 16802; (814) 865-8301.

BOOK REVIEWS

The Greening of Agricultural Policy in Industrial States: Swedish Reforms in Comparative Perspective. By David Vail, Knut Per Hasund, and Lars Drake. 1994. Cornell University Press, PO Box 6525, Ithaca, NY 14851. $45, hardcover. xiii+300 pp.

This is a valuable book in many ways, brimming with history, analyses, perspectives and lessons. It contains many discourses of varying detail, depth and length, including an extremely detailed history and account of agriculture and agricultural policy in Sweden as the context for discussion of the "greening" of agriculture in industrial societies. But even before that discussion, the authors provide a diverse and perceptive account of the various meanings of agricultural reform, including an informative discussion of the political context of green discourse and the pursuit of sustainability.

In discussing their methods, the authors are careful to make clear their point of view of "rejecting neoclassical economics' psychological/ideological postulate of radical individualism," adhering more closely to a view in which "individuals' values, needs, moral principles, decisions, and actions are all embedded in a historically evolved sociocultural matrix." Avoiding an attempt at a "grand theoretical synthesis," they opt for a narrative approach called "thick description," a term attributed to anthropologist Clifford Geertz (p. 19).

Chapters 2 through 5 go on to provide the setting: the history and evolution of Swedish agricultural policies, with intimations of the environmental and greening issues to come. It is not until Chapter 6, or 114 pages into the text, that the authors bring us to the promise of the book's title, in the chapter entitled "Greening: New Demands on Swedish Agricultural Policy." In this chapter and the following one, "Piecemeal Responses to Green Demands," the reader gets the reward for pushing through the preceding 100 or so pages on agricultural history and political economy.

Then, however, we return to more general discussion of policy in Chapter 8, "Food Policy Reform," and Chapter 9, "New Problems and Priorities in a Changing World." The concluding chapters, "Universal Greening: International Patterns," and "Globally Sustainable Agriculture in a New Millennium: Swedish Lessons," return the reader once again to the promise of the book's title.

While highly informative, rich in history, long on detail and abundant in analysis, the book overall felt to me like two books with their chapters split and shuffled to give context to the green analysis. This is a common dilemma: how much context to provide and how to provide it in a single work to draw out some learning. Both books, I presume, needed to be written: one on the historical and political-economy analysis of Swedish agriculture, the other about the growing strains and shades of green in Swedish agriculture, the explicit policy developments for environmental goals, and lessons to be learned.

This juxtaposition of context (agricultural policy) with the issue of focus (the phenomenon of greening), along with the "thick description" method, make for heavy going and cause the book to fall somewhat short of the promise of the title. (I would prefer to think of the book's title in reverse, something like "Swedish Agricultural Policy: History, Reforms, Green Trends and Implications for Industrial Societies.")

There are abundant analyses: "Since World War II, agriculture has been subject to four developments."; "The greening of the farm crisis involves a merging of three tendencies . . . "; "The Swedish agricultural policy regime comprises five core processes . . . "; "[Regarding the greening public opinion,] five main influences can be identified . . . ", to cite only a few. Which brings me to a comment on the method used. The rejection of a grand scheme of analysis in favor of thick description, coupled with a linear presentation of disjointed influential or descriptive factors, creates a maze of paths for the reader to traverse. We enter with the warning of no smoking gun or magic bullet, and exit with the declaration of some lessons learned, with thick going in between. Only late in the narrative, on page 259 of 272 pages of text, do the authors tell the reader that "a central theme in our analysis has been that getting farm input and output prices right is a precondition to achieving real consistency." I found this little reward for the work of digesting this impressive book, although the rich experience and learning that it entailed delivered many other worthwhile rewards.

There is much more to this book than an input/output model: insightful folding together of philosophical, moral and ethical issues; references to the work of sociologists and anthropologists; analysis of greening issues emerging in the popular press; a marvelous telling of the value of rural life and history to Swedes; and good discussions about the evolving metaphor of sustainability. In sum, I recommend this book to readers of many stripes, but reading it seemed at times like a mining expedition, requiring me to dig for the rich details and lessons in it and sort them out, despite the caveats and limitations the authors place upon themselves. In the end, I found myself longing for a bolder stance by the authors, thinking to myself, "all that work, and only a few lessons to show for it?" Surely there is contribution to theory to be wrested from the thick description, but perhaps it's left to the readers to spring from the thicket and develop their own ideas.

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Public Values, Private Lands: Farmland Policy, 1933–1985. By Tim Lehman. 1995. The University of North Carolina Press, PO Box 2288, Chapel Hill, NC 27515-2288. $39.95, hardcover; $16.95, paper. xii+239 pp.

Of the many resource issues affecting American agriculture, the irreversible conversion of agricultural land to other uses, such as suburban housing development, ranks among the most serious. The amount of topsoil that in effect is "lost" each year by this route is of the same order of magnitude — some billions of tons — as the amount lost to water and wind erosion. Yet the farmland preservation issue, despite having strong and highly visible advocates, often has remained distinct from broader environmental and conservation issues in agriculture. True, some individuals and organizations have concerned themselves with both,

but what seems like a natural alliance has generally been weak.

Public Values, Private Lands therefore performs a valuable service in placing farmland preservation in the larger context of agricultural conservation issues in general, and rational land use in particular. Lehman, a historian at Rocky Mountain College in Montana, presents the issue chronologically, beginning with the New Deal. The New Deal shook up every aspect of agricultural policy, and conservation was no exception: the Soil Conservation Service (SCS, now the Natural Resources Conservation Service) is among its best known and most enduring achievements. Much less well known, however, was an ambitious but largely fruitless effort to introduce systematic, county-level land use planning, which Lehman discusses in considerable detail. Had it been successful, it would have made farmland preservation part of a multi-prong conservation strategy: first, keep land in agriculture that should stay in agriculture; second, in each location, grow those crops that make the most sense, taking account of the national supply and demand situation (which in the Depression often meant surpluses), climate, soil capability, and other local factors; third, whatever crop is grown on a particular piece of land, grow it with methods that protect the soil.

The great soil conservation leaders of the 1930s, notably Hugh Bennett, viewed their mission in this broad way. However, as Lehman notes, after World War II, SCS became much more narrowly concerned with techniques, interested as much in increasing the productivity of their individual clients' land as in protecting the nation's soil. In the meantime, though, another group of people, taking a longer-range global perspective, were concerned about preserving agricultural land because of their doubts about whether yield-enhancing techniques could continue to meet the food demands of an ever-increasing world population, notwithstanding the astounding increases in output at the time.

Soil conservation and farmland preservation were reintegrated, partially, by the "World Food Crisis" and the "Energy Crisis" of the early 1970s, which showed there was common ground among the technological optimists and the doomsayers. Concerns over loss of farmland gained new urgency from the recognition that high-yield agriculture depended on nonrenewable resources and often was environmentally damaging. Lehman presents a thorough picture of this development, reflected, for example, in the much-publicized (and much-maligned) National Agricultural Lands Study done during the Carter Administration, and the flurry of land-use legislation proposed in the 1980s. He concludes his chronology with the major conservation titles of the Food Security Act (FSA) of 1985, especially the Conservation Reserve Program. He sees them as evidence that the farmland protection movement had gained renewed strength (although the conservation titles were mostly about how land was to be managed within agriculture, not whether it was to remain in agriculture). This discussion suffers from what I consider one of the book's few shortcomings — that it concentrates on the federal level, with only scant attention to state and local programs and the activities of non-profit organizations.

Having brought the story almost to the present, Lehman offers some interesting observations on its larger meaning, particularly on how farmland preservation has become integrated into the broader environmental movement. I am not thoroughly convinced on this point: for some people — although this applies more on the local level, not the national level that the book concentrates on — farmland protection still means "protect (my) open space, preferably at public expense." Lehman does not consider the extent to which preserving farmland can amount to a seemingly enlightened form of snob zoning. (Perhaps, in a perverse way, this really does support Lehman's point that farmland preservation has become part of the broader environmental movement, given the criticism sometimes raised against the environmental movement for being elitist and "anti-people," but I certainly hope not.)

Lehman tells his story well, weaving several threads together in a way that is easy to follow and that diligently avoids jargon and academese. Clearly, he has done a great deal of research, but unlike some historians, whose guiding principle even when writing for a broader audience seems to be "I worked hard to dig up this arcane fact, and I'm going to make sure you know about it, regardless of how much it gets in the way of the real story," he presents details judiciously, keeping the major themes clearly in view. I recommend it strongly not just for people concerned with farmland preservation, but for anyone interested in the full range of agriculture's environmental and conservation issues.

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Planting the Future: Developing an Agriculture that Sustains Land and Community. Edited by Elizabeth Ann R. Bird, Gordon L. Bultena, and John C. Gardner. 1995. Iowa State University Press, 2121 South State Ave., Ames, IA 50011. $14.95, paper. 276 pp.

On December 9, 1994, Senate Agriculture Committee Chairman Richard Lugar issued a series of questions about agriculture that he thought should be the focus of debate on the 1995 Farm Bill. This occurred because in November 1994 a congressional majority had been elected whose focus was on cutting the budget and reducing government's role in society. Lugar's questions centered on one basic issue: why is government involved in agriculture? In contrast, *Planting for the Future* assumes extensive government involvement in agriculture, pushing beyond a specific production approach to consider structural and social issues. But with a new Congress asking about the government's appropriate role in agriculture—for some people the question is whether the government should be involved in agriculture at all—an expanded governmental role in restructuring the sector does not seem likely.

Thus, this book unfortunately fits more into a previous agenda. One parallel might be former Secretary Bob Bergland's *Time to Choose* (U.S. Dept. of Agric., 1981), which was a superb effort to get debate underway on the important structural issues facing agriculture in the late 1970s. *Time to Choose* was comprehensive in addressing basic structural issues. It was thoroughly grounded in a good knowledge of the sector and was very well written. Policymakers and the public could appreciate its message and follow the logic of its arguments. However, it was ill-fated, even arriving late from the printer and not receiving wide distribution, since others with different views had taken

command of USDA and the agricultural agenda.

Planting the Future starts with a core of studies supported by the Northwest Area Foundation, embedding these in a broader discussion of sustainable agriculture. The objective of the Northwest Area Foundation was to "sponsor a systematic socioeconomic comparison of sustainable and conventional farming to inform taxpayers, policymakers, consumers, farmers, ranchers, environmentalists, farm groups, and others concerned about rural development" (p. xi). However, a tension results when focused, in-depth information from well-structured inquiries in four states gets expanded into a broader discussion of what is needed to promote sustainable agriculture. Leaping from the specific to the general, various authors link attributes of sustainable agriculture to broad sectoral problems.

At the beginning of the research findings we are told that "the sustainable agriculture movement represents much more than mere promotion of alternative farming practices. It also seeks fundamental social and economic reform in rural society" (p. 14). We also learn that conventional industrial farming has a dark side. To demonstrate this, a sidebar on p. 11 introduces us to two hypothetical farmers, Karl and John, from whom we learn the authors' concerns and values about conventional and sustainable agriculture. Since much of the book is based on the field studies in four states, it might have been more persuasive and engaging to use some thoughtful comments from actual farmers representing different systems instead of this mini docu-drama.

Unfortunately, this book labors under too many missions and too many contributing authors. While one team of authors is reporting important information on specific questions, like the labor and management characteristics of conventional and sustainable farms, others take on larger issues like the impact of sustainable farming on the structure of American agriculture. Whatever one's judgment about appropriate management and structure, reversing current trends is a major political undertaking quite different from the more limited concerns about farming systems. Although they are related, linking them here may not enhance better understanding of either. The structural issues are further muddied when the authors argue that sustainable agriculture's structural impact depends on how sustainability is defined. "If it is equated solely with reduced chemical use, sustainable farms in the future could be large-sized operations, and a continued decline in farm numbers and population would be expected. However, if sustainability implies the substitution of 'positive' nutrient and pest control practices for purchased production inputs, then smaller farms should prevail" (p. 81). Added to this is the notion that farmland should not be consolidated into larger units, "but instead be made available to younger farmers who are the most inclined to adopt sustainable agricultural practices" (p. 82). These two statements contain fundamental policy issues that the authors combine as part of their prescriptions for sustainable agriculture—prescriptions that are not necessarily self-evident from the area studies.

My concern here is with the difficulty in linking description and prescription. This book does not do well making good, logical connections that credibly show causal connections. The chapter on "What is Sustainable Agriculture?" adds to the confusion, presenting both broad definitions like "fundamental, holistic redesign of farming operations to emulate and use natural systems" (p. 63) alongside the more practical working definition and scoring system used in the multistate study. Presenting all these views is confusing: it might have been better just to use the operational definition and scoring system, which looked quite sensible to me. Confusion in the definition causes more confusion elsewhere, especially in the policy prescriptions.

There are format problems that highlight differences in conclusions and add to the reader's confusion. Many highlighted lists of key questions, issues and observations make the layout too dense and cluttered. More important, at times the interwoven text, sidebars and survey results seem to contradict rather than reinforce each other. For example, the text on p. 132 raises a caution about the notion that smaller sustainable farms can better support rural communities, but the sidebars on pp. 133 and 138 present a very positive picture of rural revitalization via small, sustainable farms. Finally, the survey results on p. 145 give a mixed picture.

The same confusion exists in the important chapter on the economic position and performance of sustainable farms (Chap. 6). Sidebars from a wide range of studies are interwoven with the survey results. The survey reported on specific economic characteristics of conventional and sustainable farms. The sidebars use different measures and emphasize different characteristics, giving results that sometimes are prescriptive and sometimes descriptive (sidebar 6-5 is a good example). The fractured presentation does not give a clear picture of what is going on and precludes the development of a logical argument that might convince policymakers of a particular direction they should take. In instances like this it is not clear who the intended audience is.

Today's agricultural policy spectrum ranges from efforts to abolish all farm programs to the seemingly successful efforts at the other end to maintain government payments for traditional commodity programs; in the center is a moderate effort to ask basic questions about government involvement in agriculture. This is not an environment where government is likely to be proactive about a very different structure for the agricultural sector, one that would require intense and widespread new government involvement. Like *A Time to Choose*, this book's timing is unfortunate. However, the Bergland book remains a classic primer on basic structural issues in American agriculture, with much of it as relevant today as it was a decade and a half ago. Likewise, there is some real value in *Planting the Future*. The much too short chapters on participatory research, case studies and decision cases, use of ecological methods in agriculture, geographic information systems, and overcoming barriers through cooperative research introduce topics important for all of agriculture that usually get too little attention. There also are many gems of information in the multistate studies. However, the book does not deliver on its promise of informing the public by providing a systematic socioeconomic comparison of sustainable and conventional farming. The messages are diverse and confusing, lacking the singleness of purpose, clarity, and simple logical exposition essential for a classic.

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Reference

U.S. Dept. of Agric. 1981. A Time to Choose: Summary Report on the Structure of Agriculture. Washington, DC.

BOOK NOTICES

Soil and Water Science: Key to Understanding Our Global Environment. 1994. SSSA Spec. Pub. No. 41. Soil Science Society of America, 677 South Segoe Road, Madison, WI 53711-1086. $30.00, paper. xiii+103 pp.

The result of a symposium held by the Soil Science Society of America in 1993, this collection of 10 articles covers the use and degradation of the world's soil and water resources, and strategies for conserving them. Its perspective is global, with special attention to arid regions. Major issues covered include soil erosion, water quality, irrigation, and the interaction of agriculture with global climate.

Systems Studies in Agriculture and Rural Development. J. Brossier, L. de Bonneval, and E. Landais (eds). 1994. INRA Editions, Route de Saint-Cyr, F-78026 Versailles Cedex, France. 225 FF, hardcover. 415 pp.

To give broader exposure to its agricultural development work, France's National Institute for Agricultural Research (INRA) decided to publish an English-language collection of recent papers from its Department of Agrarian Systems and Development. There are 26 papers in all, grouped under six headings: 1. Agriculture and the environment: A tightknit relationship; 2. Social elaboration of quality; 3. In support of a systems approach to animal production: Concepts, methods, results; 4. Pastoral systems and land use; 5. Agronomic theory, management sciences and decision support; and 6. Tools for regional development.

A Conspiracy of Optimism: Management of the National Forests since World War Two. Paul W. Hirt. 1994. University of Nebraska Press, 312 North 14th St., Lincoln, NE 68588-0484. $40.00, hardcover. liv+416 pp.

This treatment of the past half-century of management of the National Forests emphasizes the conflicts among different management concepts, reflected in terms such as "sustained yield," "multiple use," and "intensive management." The U.S. Forest Service is depicted as encouraging excessive extraction at the expense of destroying forest ecosystems, resulting in water pollution, declines in wildlife, and loss of scenic values. The author traces the positions of different administrations and the roles played by various interest groups.

Plants, Genes, and Agriculture. Maarten J. Chrispeels and David E. Sadava. 1994. Jones and Bartlett Publishers, One Exeter Plaza, Boston, MA 02116. $50.00, hardcover. xxiii+478 pp.

The authors of this undergraduate text say that their goals were "to teach plant biology in an agricultural context and to bridge the gap between basic and applied science." They also sought to introduce students to "the ever-changing relationship between people and their food sources." Much of the book is about the fundamental processes of plant growth and genetics, but the examples are chosen from agriculture, and there are lengthy introductory and concluding discussions of the global food situation and the world's agricultural systems.

Drought Follows the Plow. Michael H. Glantz (ed). 1994. Cambridge University Press, 110 Midland Ave., Port Chester, NY 10573. $39.95, hardcover; $19.95, paper. xviii+197 pp.

The title of this book is a reversal of the slogan "rain follows the plow," which was used to promote settlement in the semiarid Great Plains. The book's thesis is that expected climate changes and increasing population pressure will lead to even greater environmental damage as ill-adapted agricultural systems spread into increasingly arid areas. An international panel of authors examines this question for Brazil, Australia, the former Soviet Union, and several parts of Africa.

Biodiversity and Global Change. O.T. Solbrig, H.M. van Emden, and P.G.W.J. van Oordt (eds). 1994. (Revised edition; originally published 1992). CAB International. Available in U.S. from University of Arizona Press, 1230 North Park Ave., Suite 102, Tucson, AZ 85719. $33.00, paper. ix+227 pp.

"Biodiversity" as used in this book is a complex concept, referring to diversity from the molecular to the ecosystem level. Several chapters on theoretical aspects of biodiversity are complemented by specialized and often highly technical analyses of diversity as it applies to marine ecosystems, savannas, microorganisms, and many other domains. The authors are primarily from the U.S. and western Europe, with Japan and Venezuela also represented.

Sustainable Agriculture Systems. J.L. Hatfield and D.L. Karlen (eds). 1994. Lewis Publishers, 2000 Corporate Blvd., NW, Boca Raton, FL 33431. $79.95, hardcover. 316 pp.

This book is a collection of 10 chapters covering most of the topics one would expect from the title, such as weed management, insect management, and water relationships. The bulk of the chapters are on major production problems; these are framed by a historical survey, examinations of social and economic factors in the adoption of sustainable systems, and a look to the future. The authors — all from the U.S. except for one Australian — are primarily from the Midwest. Most chapters summarize a large body of literature in a short amount of space, typically running about 20 pages of text followed by at least five pages of references.

Agriculture and Environment: Bridging Food Production and Environmental Protection in Developing Countries. A.S.R. Juo and Russell D. Freed (eds). 1995. American Society of Agronomy, 677 South Segoe Road, Madison, WE 53711. $25.00, paper. xvii+275 pp.

This book comes out of a 1993 Agronomy Society symposium that dealt with technological, social and cultural factors in the adoption of environmentally sound production systems in the developing world. Its 13 papers are mostly by U.S. authors, but India, Japan, Poland and Nigeria are also represented. Some of the papers are about specific technological areas, such as agrochemicals, biotechnology, control of non-point source pollution, and crop protection. Others are about particular production situations, such as paddy rice, semiarid agriculture, and agroforestry. The book also covers institutional issues such as watershed-level planning, the role of agronomists, and agricultural research policy.

Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Julian M. Alston, George W. Norton, and Philip G. Pardey. 1995. Cornell University Press, PO Box 250, Ithaca, NY 14851. $39.95, hardcover. xxxiii+585 pp.

The rationale for this book is that with budgets shrinking, agricultural research administrators must do a better job in choosing priorities and assessing the value of what gets done with the money. This is especially true when, as is true in so many countries, research institutions are expected to take on a wider range of issues, such as environmental quality, despite reduced budgets. The authors all are economists, and their approach is strongly dominated by economics. Many of the chapters are extremely technical, often involving complex mathematical models and highly formal analyses.

RESOURCES

"Sustainable Agriculture Decision Cases," written and video materials, $25, and **"Sustainability: The Quiet Revolution,"** a 45-minute video, $45, are available from Minnesota Extension Service Distribution Center, 20 Coffey Hall, 1420 Eckles Ave., St. Paul, MN 55108-6069; (612) 625-8713.

"International Erosion Control Association Products and Services Directory" is available from IECA, 1-800-455-4322, or (303) 879-3010.

"Animal Agriculture: Information on Waste Management and Water Quality Issues" (GAO/RCED-95-200BR) is free from the U.S. General Accounting Office, P.O. Box 6015, Gaithersburg, MD 20884-6015; (202) 512-6000; fax (301) 258-4066.

"Proceedings of the Northeast Farmer to Farmer Information Exchange," on five topics, are $3.95 for 1–3 copies, or $2 for 4 or more, plus 10% of total for shipping; topics are Apples, Greenhouse, Livestock, Strawberries, and Sweet Corn; contact Northeast Organic Farming Association, 411 Sheldon Road, Barre, MA 01005; (508) 355-2853.

"Conserving Land: Population and Sustainable Food Production" is available from Population Action International, 1120 19th St., NW, #550, Washington, D.C. 20036; (202) 659-1833; or on the Internet: search for "gopher.igc.org" and look for "Population Action International/" among "Organizations on the IGC Networks Gopher/."

"Challenge and Change: A Progressive Approach to Pesticide Regulation in California" is available from Dr. Tobi Jones, Special Assistant for Outreach and Special Projects, Department of Pesticide Regulation, 1020 N St., Sacramento, CA 95814; (916) 445-3931.

"Udder Sense — Low-Cost/Sustainable Strategies of Resourceful Dairy Farmers" is $10 from the Center for Rural Affairs, P.O. Box 406, Walthill, NE 68067.

Sustainable Agriculture Network information available includes "The Sustainable Agriculture Directory of Expertise," $14.95; "Managing Cover Crops Profitably," $9.95; "Showcase of Sustainable Agriculture Information and Educational Materials," $4.95; "The Real Dirt," $13.95; "SARE/ACE Research Summaries," $7.50; "Sustainable Agriculture vs. Weeds," free; and "Getting Started Electronically With the Sustainable Agriculture Network," free; contact Sustainable Agriculture Publications, Hills Building, UVM, Burlington, VT 05405; (802) 656-0471.

"Biomass Resources in Arkansas" is available from Winrock International Institute for Agricultural Development, Petit Jean Mountain, Route 3, Box 376, Morrilton, AR 72110; (501) 727-5435; e-mail receptionist@winrock.org

"Agroforestry and Sustainable Systems: Symposium Proceedings," from an August 7–10, 1994, symposium in Fort Collins, CO, is available from USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, National Agroforestry Center, East Campus-UNL, Lincoln, NE 68583-0822; (402) 437-5178.

"Greenbook '95" is available from the Energy and Sustainable Agriculture Program, Minnesota Dept. of Agriculture, 90 West Plato Blvd., St. Paul, MN 55107; (612) 296-7673.

"Alternatives to Methyl Bromide: Research Needs for California" is free from California Department of Food and Agriculture's Office of Pesticide Consultation, 1220 N St., Sacramento, CA 95814; (916) 654-1765.

"Land-Grant University Agricultural and Natural Resources Research" and **"Science-Sustainability"** are free; **"The 'Sondeo,' "Focus Groups," "Ground Rules Equalize Power as Governmental Agencies Manage Citizen Involvement," "Volunteers as Partners in Community Action," "Developing Community Participation and Consensus,"** and **"The Community Survey"** are $1 from Bulletins Office, Cooperative Extension, Cooper Publication Building, Washington State University, Pullman, WA 99164-5912; (509) 335-2857.

"List of Information Products," "Sustainable Agriculture in Print: Current Periodicals," and **"Videocassettes in the NAL Collection Pertaining to Alternative Farming Systems"** are available from Alternative Farming Systems Information Center, National Agricultural Library, Room 304, 10301 Baltimore Blvd., Beltsville, MD 20705; (301) 504-6559; e-mail afsic@nalusda.gov

"Reaping What We Have Sown: Public Policy Consequences of Agricultural Industrialization and the Legal Implications of a Changing Production System," White Paper 95-1, is available from Drake University Law School, Agricultural Law Center, Des Moines, IA 50311; (515) 271-2065.

"A Conservation Breeding Handbook" is $12.95 plus $3 shipping from American Livestock Breeds Conservancy, P.O. Box 477, Pittsboro, N.C. 27312; (919) 542-5704.

"Our Field: A Manual for Community Shared Agriculture" is $15 from Tamsyn Rowley, Department of Environmental Science, University of Guelph, Guelph, Ontario, N1G 2W1, Canada; (519) 824-4120 ext. 3675; e-mail trowley@envsci.uoguelph.ca

"Waste Management and Utilization in Food Production and Processing," 125 pages, is $22 from the Council for Agricultural Science and Technology, 4420 West Lincoln Way, Ames, IA 50014-3447; (515) 292-2125.

Guide for Authors

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Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted.

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The title page should give the following information (all flush left): 1) title of the paper; 2) names of authors; 3) affiliation and office address of authors, and 4) disclaimers and publication number, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single-discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key words

Provide subject matter key words suitable for use in scientific indexing.

Reference list

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized.

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Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

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